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CORRECTING FEED DISPLACEMENTS IN A SPACE FED LENS ANTENNA

Randy L. Haupt, Captain, USAF

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Feed deformations in a space fed lens may seriously degrade the antenna's far field pattern. The errors in the far field pattern due to the deformations may be reduced by appropriately adjusting the phase shifters in the feed and/or lens. A linear model was used to determine and correct for feed tilt, fold, lateral far field pattern distortions due to displacement, perpendicular displacement, and any combination of these errors. Lens corrections align the main beam on boresite, while feed corrections restore gain and sidelobe levels.

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Combining the feed and lens corrections almost totally restores the original far field pattern.

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Contents

Illustrations

Tables

Correcting Feed Displacements in a Space Fed Lens Antenna

I. INTRODUCTION

Very large phased array antennas are difficult to build. In addition to their being expensive, they are heavy, bulky, and complex. One step toward reducing the weight, expense, and complexity is to replace the corporate feed with a space feed. A space feed has the advantage of eliminating many of the antenna's components. A space feed has no physical connections between the elements in the array and the transmitters and receivers. Thus, the heavy waveguides, power dividers, coaxial cables, and so on, are eliminated. Instead, a phased array feed of NF elements transmits to and receives from the NL elements of the main aperture (NF < NL).

Figure 1 is a model of a space fed lens antenna. The small array on the left side of the picture is the feed. It contains the transmitters, receivers, power generating equipment, and signal processing of the system. In addition, each element has control of the phase and amplitude of the signal it radiates. Unlike the feed, the lens has no amplifiers. However, every lens element has a phase shifter for steering the antenna's mainbeam and compensating for the nonplanar wavefront incident on the back of the lens from the feed. In this case, the lens does not have an amplitude taper for low sidelobes because the feed radiation pattern generates the required amplitude taper on the back of the lens.

(Received for publication 29 September 1983)

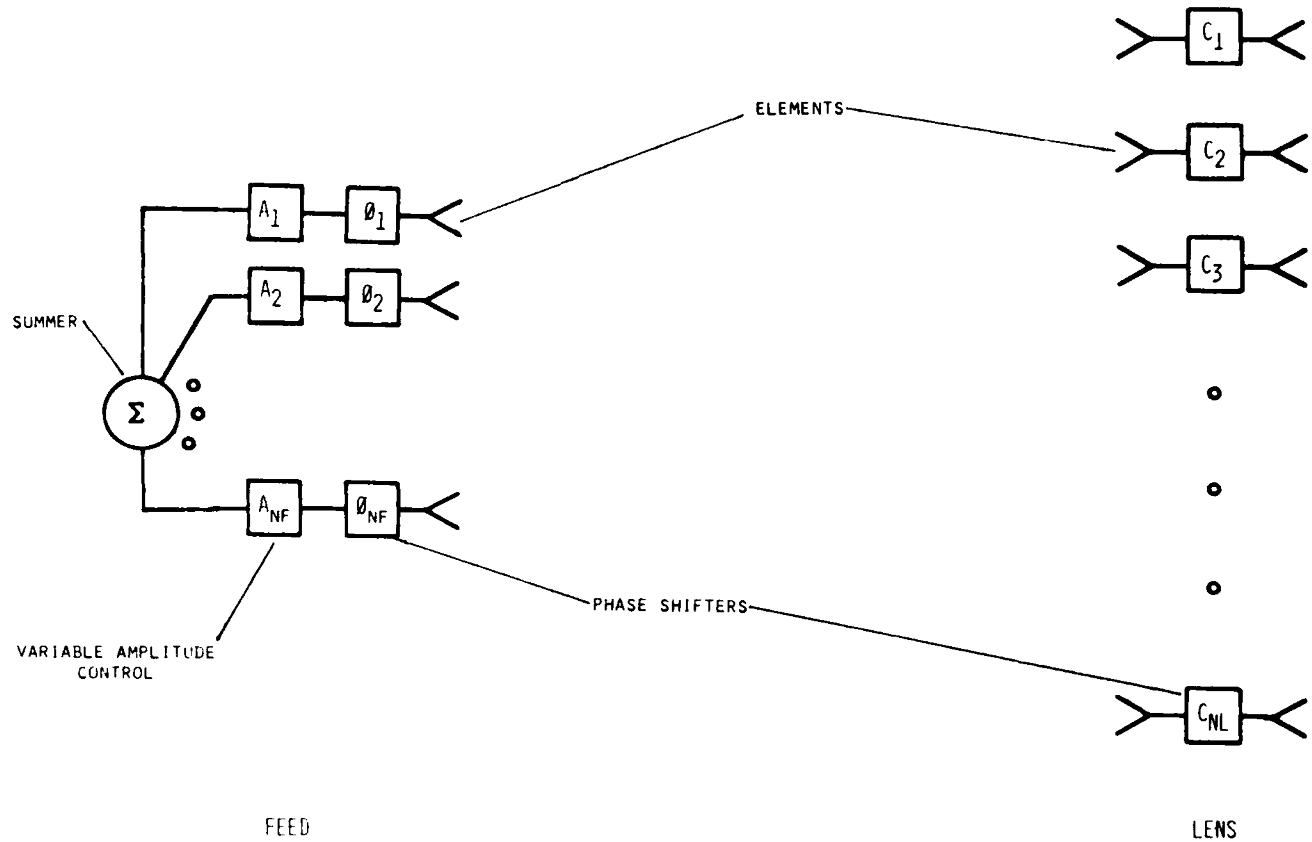

Figure 1. Model of a Space Fed Lens Antenna

The space fed lens has several advantages over a corporate fed phase array:[1]

(1) There are no transmission line feed networks,

(2) The feed provides a natural amplitude taper,

(3) The feed can easily generate multiple beams,

(4) A transmitter or receiver does not have to be at every element in the lens.

On the other hand, some of the disadvantages of a space fed lens are:

(1) Feed spillover,

(2) Limited power,

(3) Outside interference to the feed, and

(4) Feed displacement.

Feed displacement occurs when the feed is not at its precise design location. The displacement may be due to a deployment malfunction or uneven heating from the sun. When the feed moves out of place, the phase and amplitude taper radiated on the back of the lens changes. The lens phase shifters no longer correct for the non-planar wavefront and the low sidelobe amplitude taper changes. Consequently, the antenna's far field pattern degrades (lowers gain and raises sidelobes). The resulting far field pattern may produce unacceptable performance, especially if the displacement is large and the far field sidelobes are low. Unless a method is contrived to correct for the displacement the antenna system may be useless.

One way to correct the feed displacement is to have a technician reposition the feed. This solution is unrealistic, though, when the antenna is in an unattended location and continuous adjustments are necessary. A second method to realign the feed is to mechanically move it back into place. This method can correct deployment errors, but cannot compensate for the thermal expansion. Finally, the displaced feed can be compensated by adjusting the phase and amplitude of the feed elements and/or the phase of the lens elements to reproduce the desired field distribution on the back of the lens. This solution compensates for both deployment and thermal displacements. The last compensation technique is the central topic of this report.

2. ANALYSIS

In the analysis that follows, we assume that the feed has NF equally spaced isotropic elements. Likewise, the lens has NL equally spaced isotropic elements. In the quiescent state, the feed and lens are parallel to each other and have a

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1. Skolnick, Merrill I. (1980) Introduction to Radar Systems, McGraw-Hill Book Co., New York, pp. 308-309.

separation distance of R in wavelength (λ). Assuming that feed element m has an amplitude taper given by a_m and a phase ϕ_m, the electric field intensity on the back of the lens is given by

$$E_n = \sum_{m=1}^{NF} \frac{1}{R_{nm}} e^{-j 2\pi R_{nm}} (a_m e^{j\phi_m}) \tag{1}$$

where

R_{nm} = distance in λ from element m of the feed to element n of the lens.

The elements on the backside of the lens receive the signals from the feed, pass the signals through the phase shifters, and reradiate the signals from the elements on the front side of the lens. We will assume the elements are perfectly matched and receive all the signals incident on the back of the lens. Also, the phase shifters in this model are lossless. The phase shifter at each element applies a correction factor, C_n, to correct for the non-planar phase front radiated by the feed. C_n is the phase shift necessary to cancel the signal phase at element n. In addition, a linear phase shift may be superimposed on the correction factor to steer the main beam. For the purposes of this analysis, however, we will assume the main beam is on boresite (θ = 0°). From the above information, the far field pattern of the antenna is given by

$$F = \sum_{n=1}^{NL} E_n e^{-jC_n} e^{jd_n u} \tag{2}$$

$$= \sum_{n=1}^{NL} \sum_{m=1}^{NF} \frac{a_n}{R_{nm}} e^{j(d_n u + \phi_n - C_n - 2\pi R_{nm})} \tag{3}$$

where

$u = \sin\theta$
θ = angle from boresite
$d_n = d_o (n - 0.5 - NF/2)$
d_o = element spacing of lens.

Equations (2) and (3) hold true for a distorted or a nondistorted feed. The variable R_{nm} takes into account any feed distortions. If (Xf_m, Yf_m) and (Xl_n, Yl_n) represent the coordinates for the field and lens elements respectively, then the distance from feed element m to lens element n is

$$R_{mn} = \sqrt{(X1_n - Xf_m)^2 + (Y1_n - Yf_m)^2} \ . \tag{4}$$

Four different distortions were considered in the model: linear tilt, linear fold, parallel displacement, and perpendicular displacement. Each of these is displayed in Figure 2. When the feed has a linear tilt of Ψ, the element locations are given by

$$(Xf_m \cos \Psi, \ Xf_m \sin \Psi + R) \ . \tag{5}$$

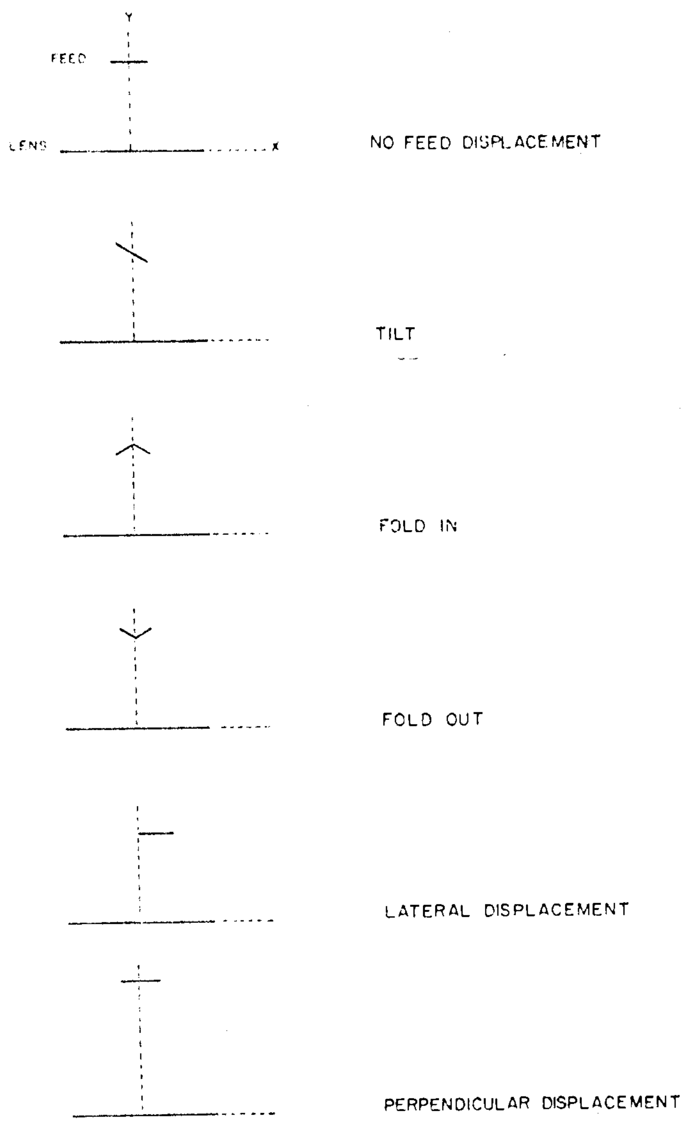

Figure 2. Types of Feed Distortions

The variable Xf_m is the x-coordinate of element m (in λ). A linear fold occurs when the feed bends in the middle and the two ends of the array bend toward the lens or away from the lens. The element coordinates for the fold-in are $(Xf_m \cos\Psi, -|Xf_m| \sin\Psi + R)$ and for the fold-out $(Xf_m \cos\Psi, |Xf_m| \sin\Psi + R)$. Finally, the feed can be distorted by a constant displacement along the y-axis with element location $(Xf_m, R + y_c)$ or along the x-axis with new element locations given by $(Xf_m + x_c, R)$. Any combination of the above distortions is possible.

The simulation of the space fed lens had 6 feed elements and 30 lens elements. Both arrays had element spacing of 0.5 λ and were separated by a distance $R = 18\,\lambda$. The feed weights were chosen to yield a low sidelobe amplitude taper on the back of the lens. Figure 3 shows the resulting far field pattern of the lens (neglecting spillover). The amplitude and phase values for the feed and lens elements are given in Table A1 of the Appendix. This far field pattern is the quiescent pattern and will serve as the desired reference in future calculations

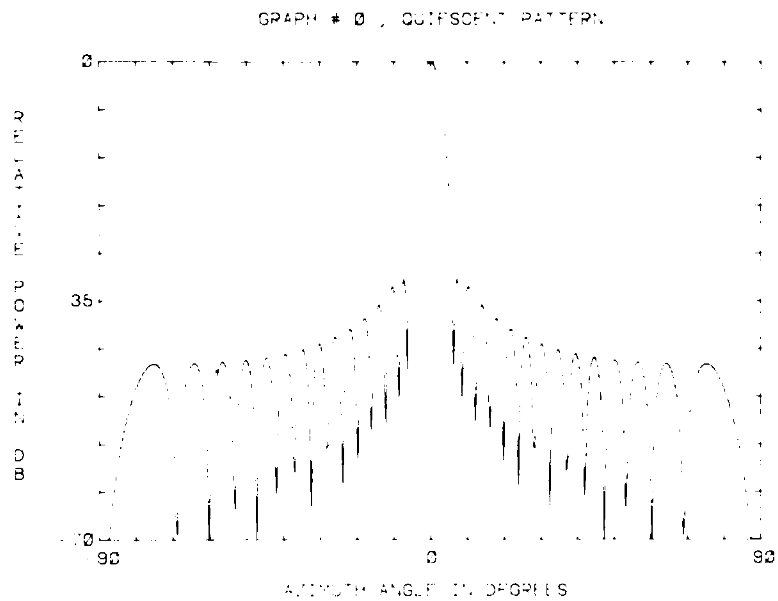

Figure 3. Quiescent Far Field Pattern of a 6 Element Feed and 30 Element Lens

Examples of the far field patterns due to each of the distortions are shown in Figures 4 to 8. Their associated feed and lens distributions are shown in Tables A2 to A6. Figure 4 has a 10° tilt on the feed, Figure 5 a 10° fold out, Figure 6 a 2λ parallel displacement, and Figure 7 a 2λ perpendicular displacement. The far field pattern in Figure 8 is the far field pattern due to a 10° tilt, a 2λ parallel displacement, and a 2λ perpendicular displacement. Each of the feed distortions causes unacceptable degradation to the antenna's far field pattern. The three major effects of the distortion are lower gain, raised sidelobes, and the mainbeam is steered in the wrong direction. To correct for these distortions, adjustments are made to the signals in the lens and/or feed. These adjustments help restore the desired phase and amplitude distribution on the back of the lens without physically moving the feed.

The first type of correction only used the lens phase shifters. Since the feed is distorted, the signal received by the elements on the back of the lens is no longer the same as in the quiescent case. Thus, the amplitudes of these signals differ from the quiescent condition and the phases are no longer cancelled by the lens phase shifter settings, C_n. By setting the lens phase shifters to a new $\tilde{C}_n$, they negate the phase of the distorted signal. Nothing can be done about the distorted amplitude taper because the lens has no amplitude control over the signals. This type of compensation was tried on the five distortions discussed before. The resulting patterns appear in Figures 9 to 13. Phase only lens compensation provided *significant improvements for the perpendicular* displacement and the fold-in distortion cases. The new phase shifter settings steered the mainbeam back to the desired location for the parallel displacement case, but made no noticeable improvement to the sidelobe levels. Finally, the lens correction made no improvements on the far field pattern when the feed was tilted at an angle of 10°. When the tilt and displacement distortions were combined, the lens correction steered the beam back to boresite, but made no improvements to the sidelobe level.

The phase only lens corrections work well when the distorted amplitude distribution on the back of the lens is symmetrical. If the amplitude distortion is skewed, the far field sidelobes go up relative to the mainbeam. This occurs when the feed distortion is not symmetrical about the y-axis. If the feed distortion causes the lens mainbeam to steer off boresite, the lens correction steers the main beam back to boresite.

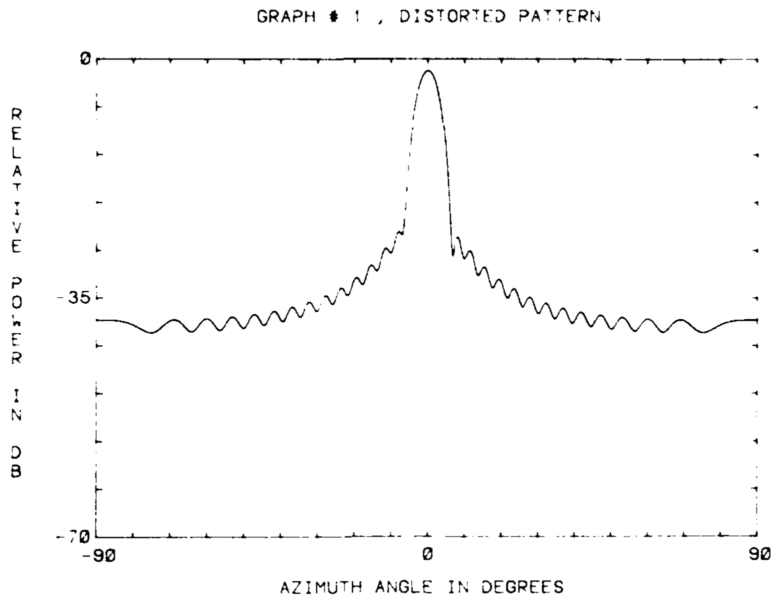

Figure 4. Far Field Pattern When the Feed Has a 10° Linear Tilt

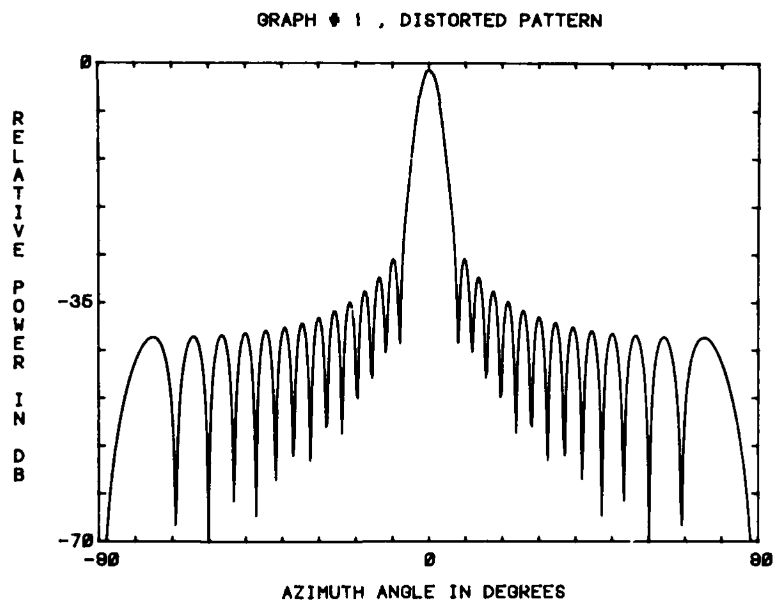

Figure 5. Far Field Pattern When the Feed Has a 10° Linear Fold Away From the Lens

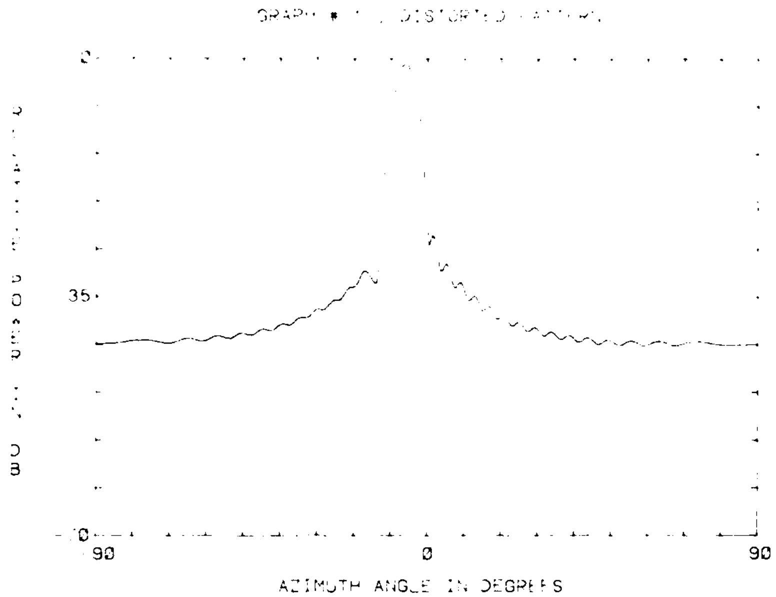

Figure 6. Far Field Pattern When the Feed Has a 2λ Parallel Displacement

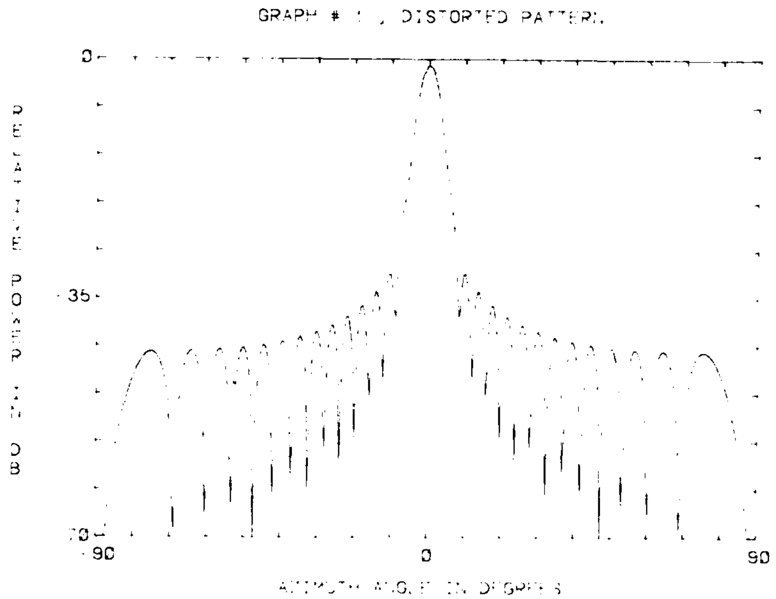

Figure 7. Far Field Pattern When the Feed Has a 2λ Perpendicular Displacement

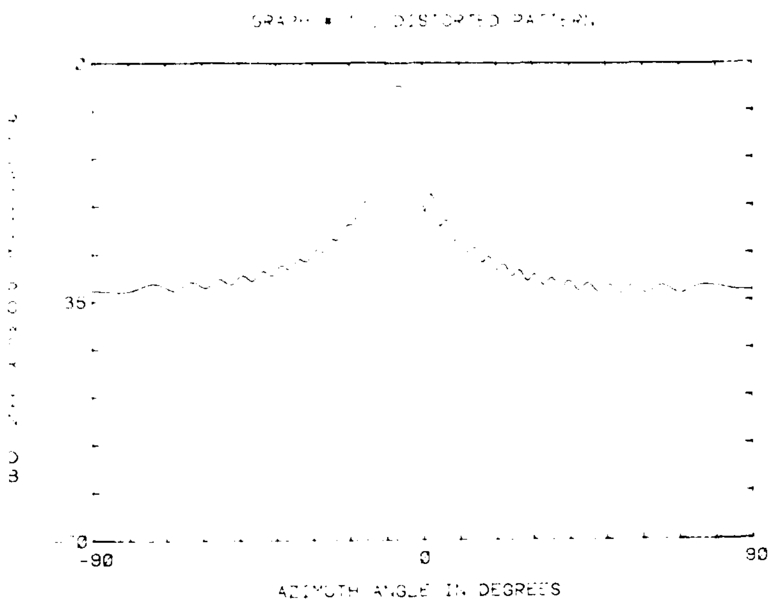

Figure 8. Far Field Pattern When the Feed Has a 10° Linear Tilt, 2λ Parallel Displacement, and a 2λ Perpendicular Displacement

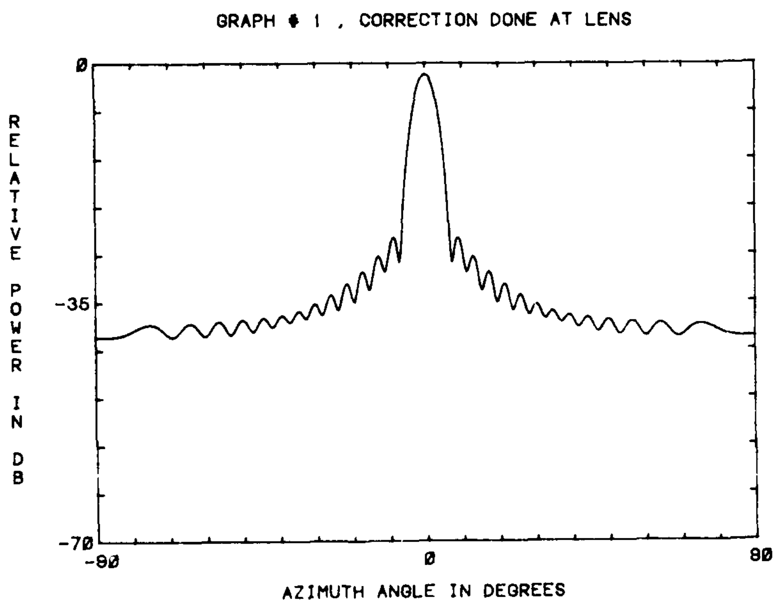

Figure 9. Far Field Pattern When the Feed Has a 10° Linear Tilt and Phase Only Lens Compensation

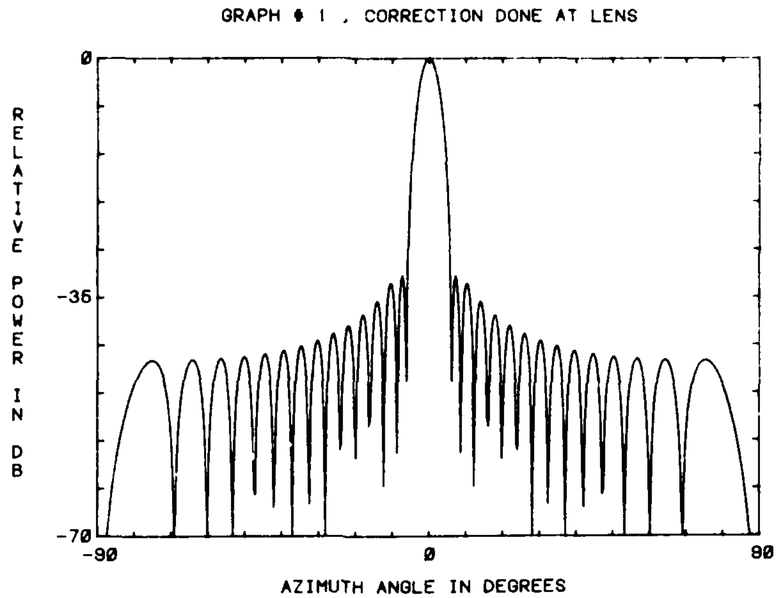

Figure 10. Far Field Pattern When the Feed Has a 10° Linear Fold and Phase Only Lens Compensation

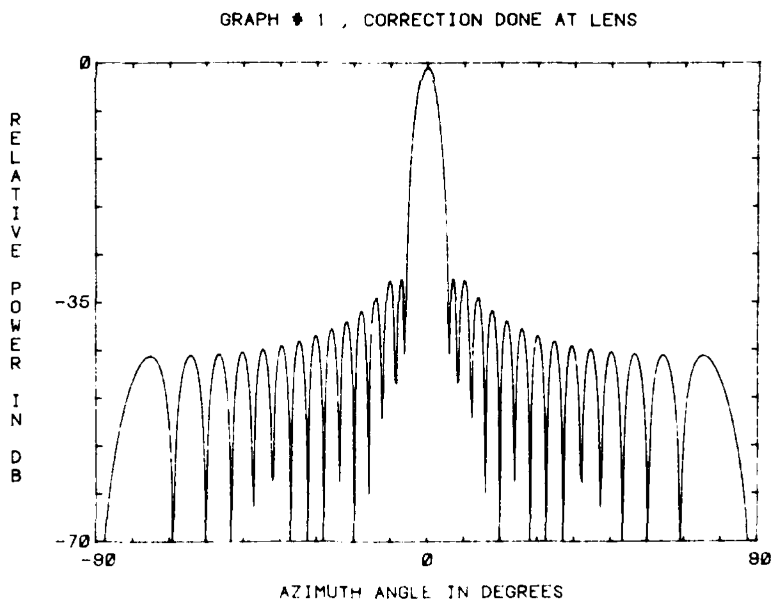

Figure 11. Far Field Pattern When the Feed Has a 2λ Parallel Displacement and Phase Only Lens Compensation

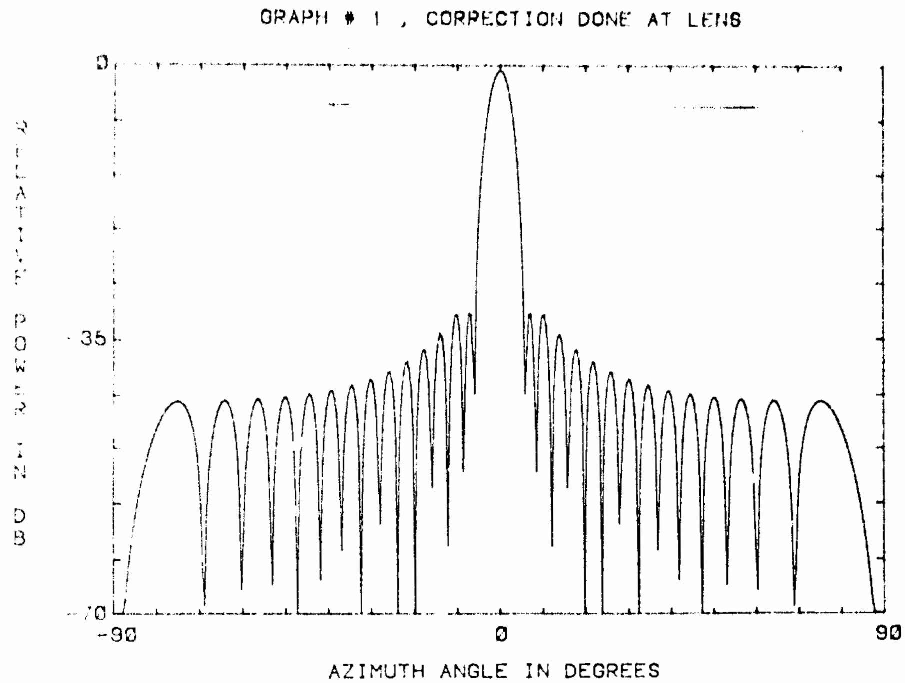

Figure 12. Far Field Pattern When the Feed Has a 2λ Perpendicular Displacement and Phase Only Lens Compensation

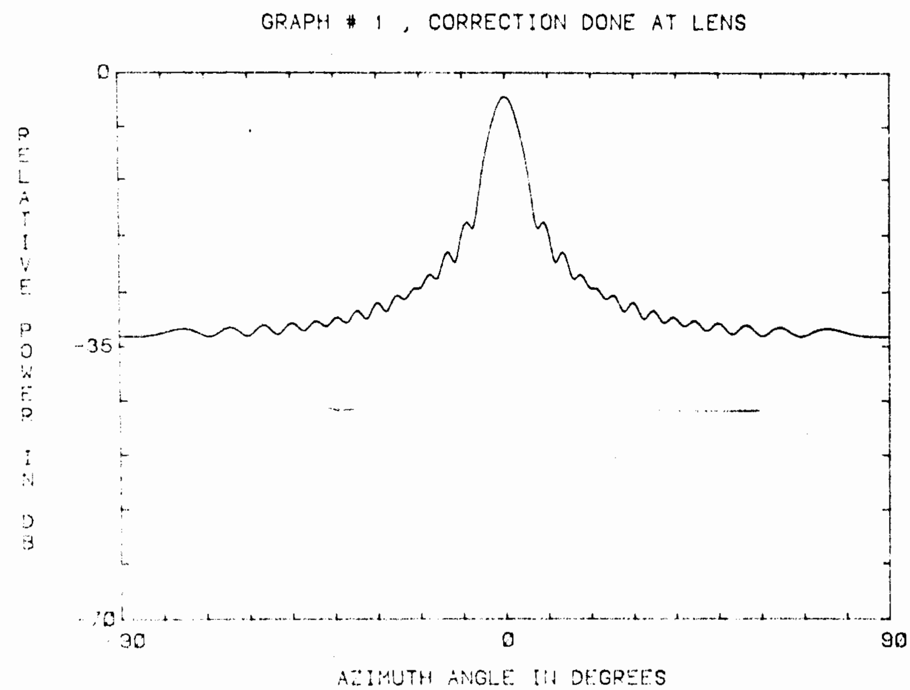

Figure 13. Far Field Pattern When the Feed Has a 10° Linear Tilt, 2λ Parallel Displacement, and a 2λ Perpendicular Displacement and Phase Only Compensation

Properly adjusting the phase and/or amplitude at each feed element can also compensate for the feed displacement. The values for the feed weights, A_m, are formed by calculating the field intensity radiated by the lens on each feed element.

$$A_m = \sum_{n=1}^{N} b_n e^{j(C_n - 2\pi R_{nm})} . \tag{5}$$

Taking the complex conjugate of A_m yields the new feed weights. Next, the new feed weights are transformed back to the lens.

$$B_n = \sum_{m=1}^{M} A_m^* e^{-j 2\pi R_{nm}} \tag{6}$$

The field intensity on the back of the lens does not equal the desired value. Thus, the phase values of C_n = phase $\left\{ B_n \right\}$ are kept, but the desired amplitude values of b_n are substituted for $|B_n|$. Now, the desired amplitude values and the calculated phase values are transformed back to the feed to obtain the new feed weights. This process repeats until the feed weights converge on the values that yield an amplitude and phase distribution on the back of the lens that is very close to the desired distribution.

The first computer runs had phase only compensation at the feed, without any lens correction. Phase only compensation retains the phase $\left\{ A_m \right\}$ from Eq. (5), but keeps the original feed amplitude weights a_m. Figures 14 to 18 display the results of phase-only feed compensation on the five distorted cases. The new feed weights and the resulting amplitude and phase distribution on the back of the lens are shown in Tables A7 to A11 in the Appendix. In all cases, the phase-only feed compensation lowered the sidelobe levels of the antenna to almost the same level as the quiescent far field pattern. However, this compensation did not steer the mainbeam back to boresite when the feed was displaced parallel to the lens (Figures 17 and 18).

The next attempt at feed compensation adjusted the amplitude as well as the phase of the feed elements. This means the amplitude and phase of A_m in Eq. (5) are kept in the iterative process of finding the feed weights. Amplitude and phase compensation at the feed offered no advantages over the phase only compensation. In fact, the amplitude and phase iterative process takes much longer to converge than the phase only process. Moreover, the final amplitude feed weights and phases are the same as that obtained from the phase only feed compensation. As far as correcting for feed displacement phase-only correction at the feed is more appealing than amplitude and phase corrections.

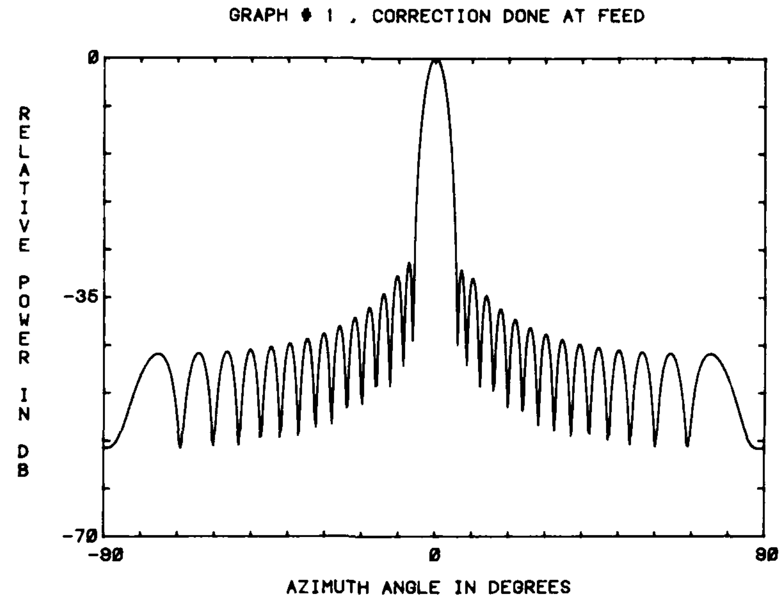

Figure 14. Far Field Pattern When the Feed Has a 10° Linear Tilt and Phase Only Feed Compensation

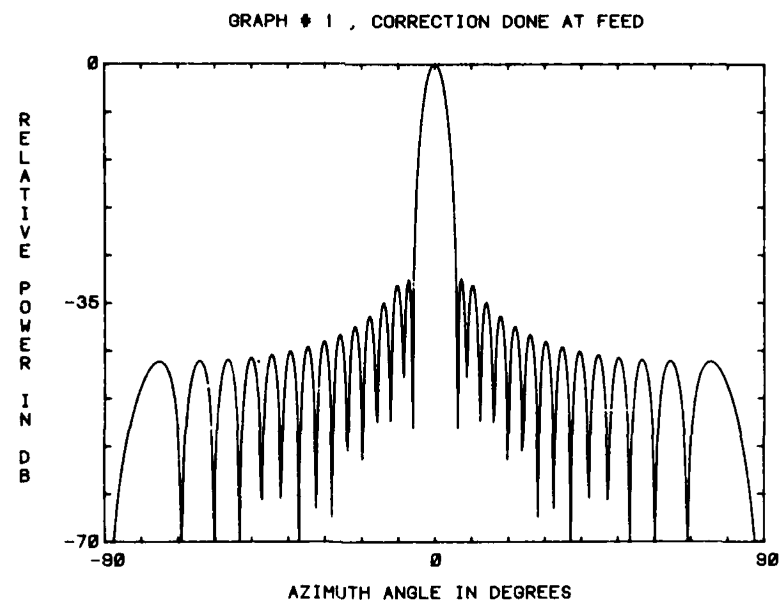

Figure 15. Far Field Pattern When the Feed Has a 10° Linear Fold Away From the Lens and Phase Only Feed Compensation

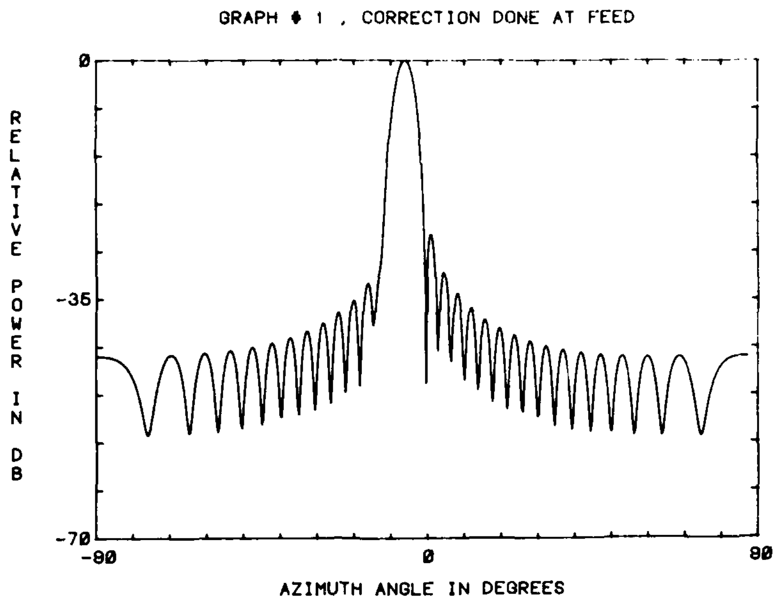

Figure 16. Far Field Pattern When the Feed Has a 2λ Parallel Displacement and Phase Only Feed Compensation

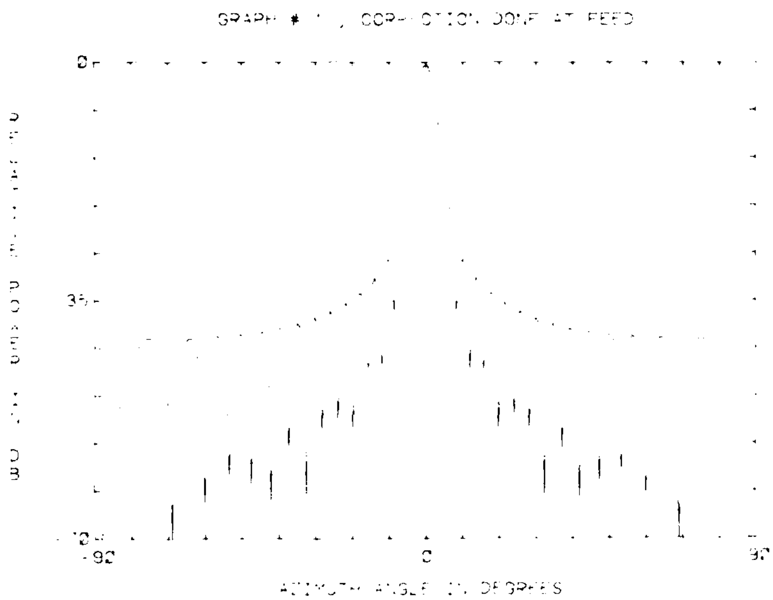

Figure 17. Far Field Pattern When the Feed Has a 2λ Perpendicular Displacement and Phase Only Feed Compensation

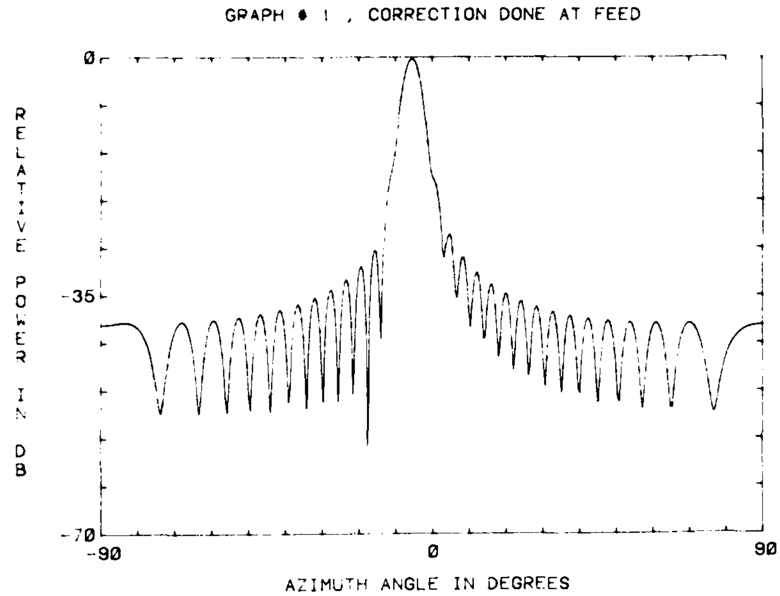

Figure 18. Far Field Pattern When the Feed Has a 10° Linear Tilt, 2λ Parallel Displacement, and a 2λ Perpendicular Displacement and Phase Only Feed Compensation

The next step incorporates both the phase-only feed and lens compensation. This technique uses the compensated feed weights in Tables A7 to A11. Additionally, the lens correction is set equal to the negative phase of the signal incident on the back of the lens at each element. The far field patterns in Figures 19 to 21 show little improvement over the previous feed compensation cases. As expected, the main beams in Figures 22 and 23 were steered back to boresite. One can conclude from the computer runs that feed correction restores the sidelobe structure, while the lens correction realigns the main beam.

3. PRACTICAL CONSIDERATIONS

The modelling in the last section disregarded mutual coupling between elements, spillover, reflections, quantization errors, element taper, bandwidth, and element location errors. These assumptions cannot be made in a realistic situation. This section looks at three improvements to the ideal model. They are phase quantization, element pattern, and feed element failures.

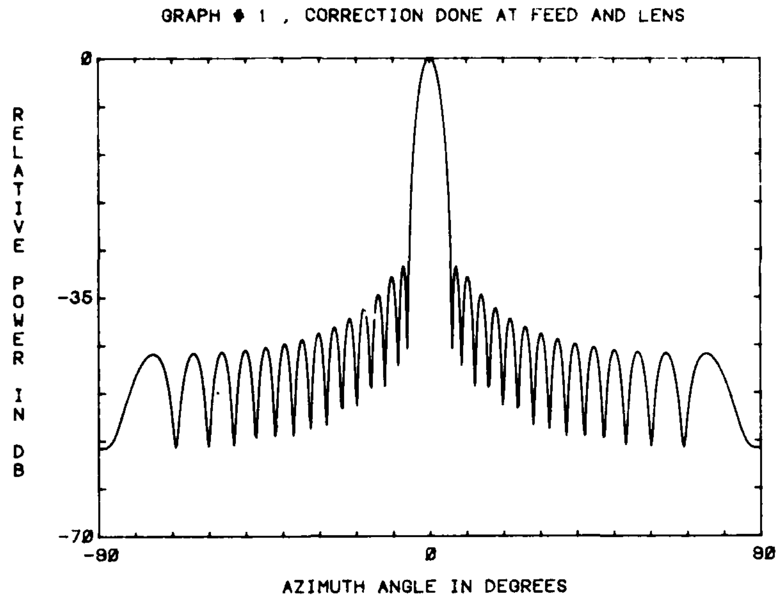

Figure 19. Far Field Pattern When the Feed Has a 10° Linear Tilt and Phase Only Feed and Lens Compensation

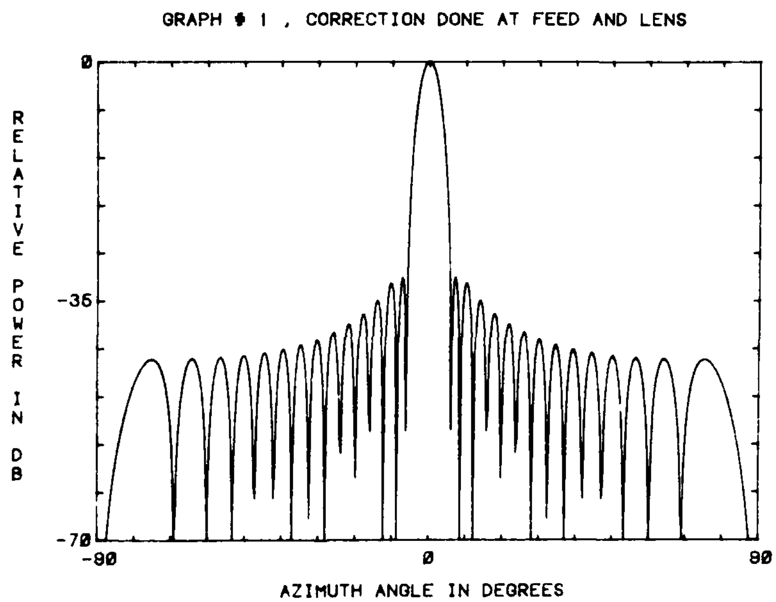

Figure 20. Far Field Pattern When the Feed Has a 10° Linear Fold Toward the Lens and Phase Only Feed and Lens Compensation

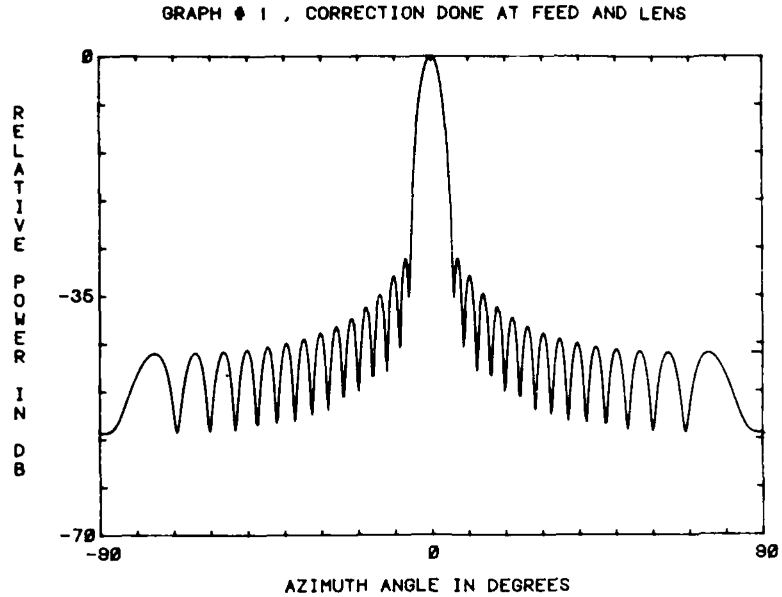

Figure 21. Far Field Pattern When the Feed Has a 2λ Parallel Displacement and Phase Only Feed and Lens Compensation

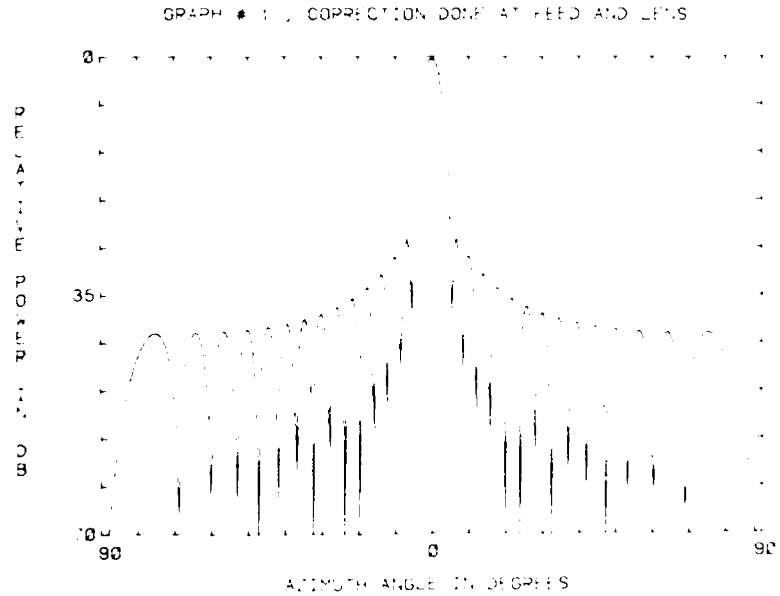

Figure 22. Far Field Pattern When the Feed Has a 2λ Perpendicular Displacement and Phase Only Feed and Lens Compensation

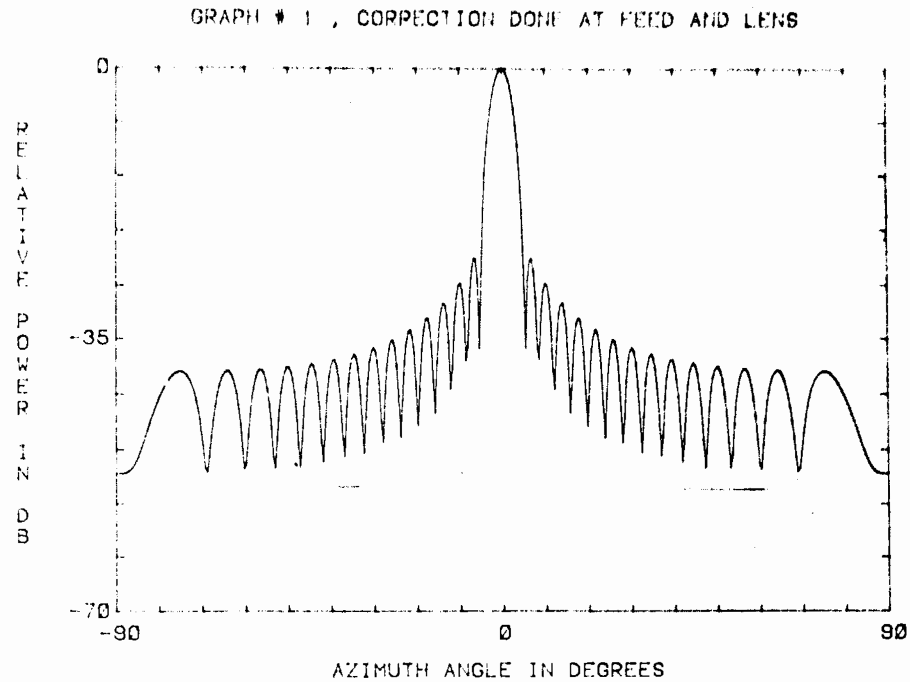

Figure 23. Far Field Pattern When the Feed Has a 10° Linear Tilt, 2λ Parallel Displacement, and a 2λ Perpendicular Displacement and Phase Only Feed and Lens Compensation

Phase quantization at the feed and lens approximates the true phase values by the equation

$$\phi_T \simeq \phi_Q = Q \times \text{INTEGER} \left\{ \phi_T / Q \right\} \tag{7}$$

where

Q = quantization level = $2\pi / 2^B$,

B = number of bits in phase shifter,

ϕ_T = true phase shift,

ϕ_Q = quantized true phased shift.

INTEGER $\left\{ X \right\}$ - rounds X to nearest integer.

Increasing the number of bits in the phase shifter improves the accuracy of the approximation $\phi_T \simeq \phi_Q$. More bits mean a higher cost too. A trade-off must be made to determine the quantization level necessary to produce the desired gain and sidelobe levels. The answer will be a function of the number of elements in the feed and lens as well as the antenna's performance specification.

A cosine squared element pattern was chosen to use in the model. This pattern has a 3 dB beamwidth of 90°. Since the beamwidth is wide, the field intensity on the back of the lens will not vary much from the isotropic element case.

To demonstrate the effects of phase shifter quantization, and element pattern taper on the compensation techniques, the 10° linear tilt distortion case serves as an example. Four bit phase shifters were used in the six element feed and 30 element lens. Figure 24 is the new quiescent pattern. Sidelobes beyond the second sidelobe are much higher than the same sidelobes in Figure 3. The distorted pattern with phase quantization and cosine squared element pattern appears in Figure 25. Figure 26 shows the lens correction, Figure 27 is the far field pattern with phase-only feed correction, and Figure 28 combines the feed and lens corrections. As in the previous examples, the lens correction had little impact, but the feed correction came close to restoring the quiescent pattern. The sidelobes in Figure 28 are slightly higher than those in Figure 24. Phase shifters with 5 or 6 bit accuracies produce better results than the 4 bit phase shifters. The amplitude and phase distribution for these runs are shown in Tables A12 to A16 in the Appendix.

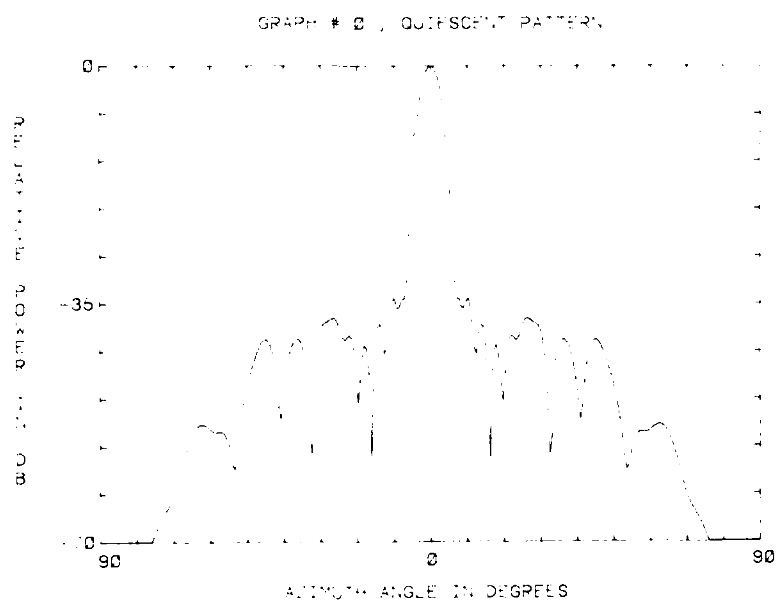

Figure 24. Quiescent Far Field Pattern With Four Bit Phase Shifters and a Cosine Squared Element Pattern

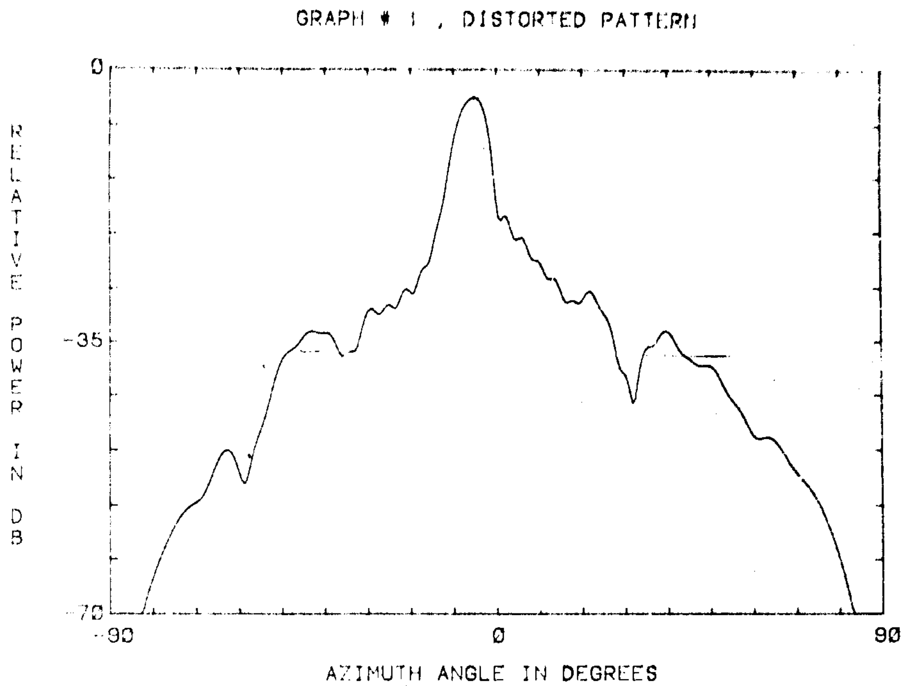

Figure 25. Distorted Far Field Pattern Including the Effects of Shift Quantization and Element Pattern

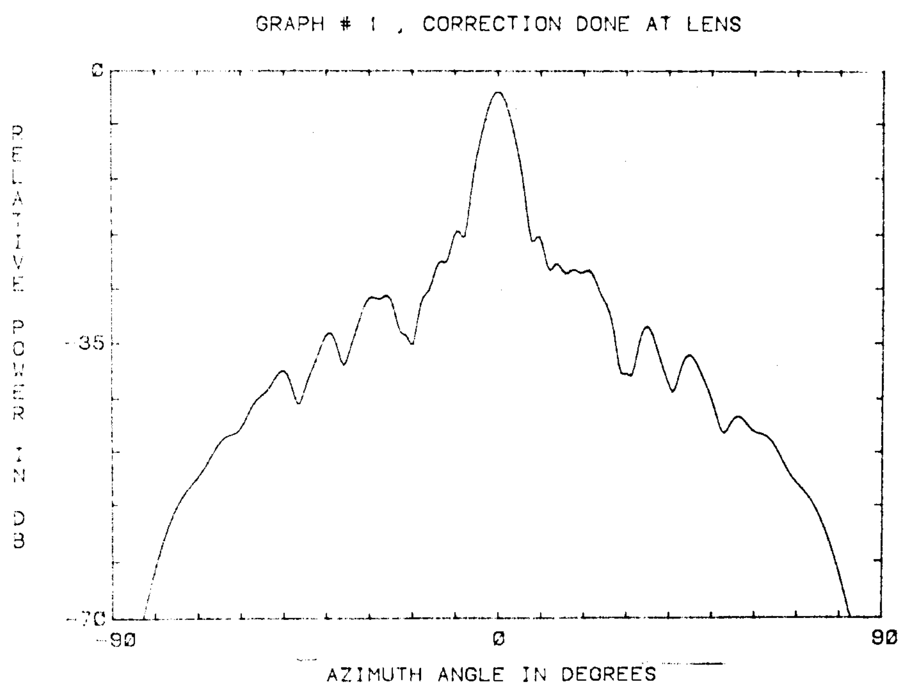

Figure 26. Distorted Far Field Pattern Corrected by Four Bit Phase Shifters in the Lens

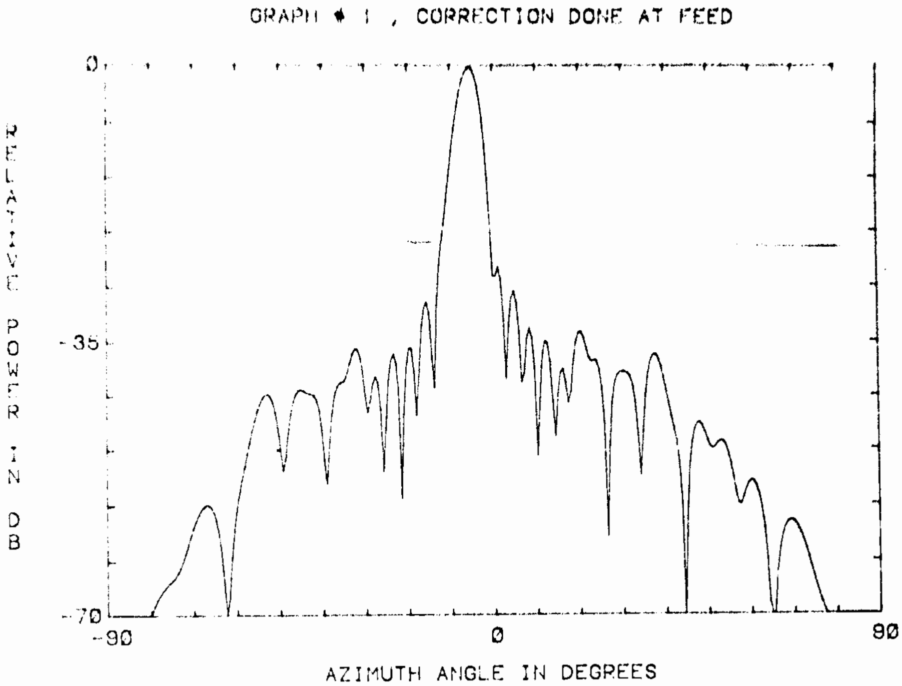

Figure 27. Distorted Far Field Pattern Corrected by Four Bit Phase Shifters in the Feed

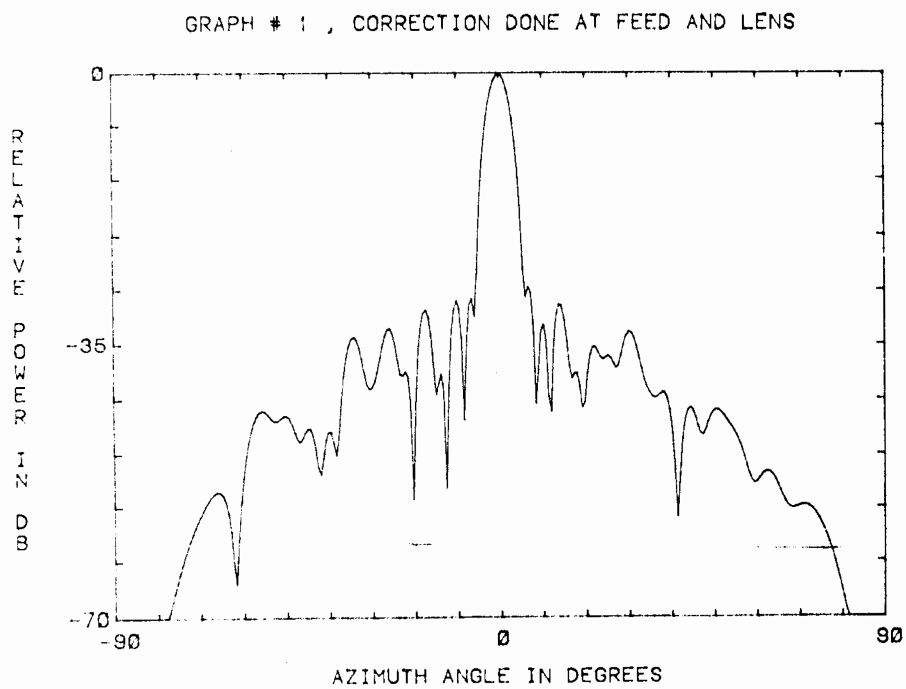

Figure 28. Distorted Far Field Pattern Corrected by Four Bit Phase Shifters in the Feed and Lens

Another problem that can arise after deploying the antenna is element failure. If one of the elements in the feed no longer radiates, the amplitude and phase distribution on the back of the lens changes. For instance, consider the situation when element 1 (an edge element) of the feed fails. The new amplitude and phase distribution on the back of the lens is shown in Table A17 of the Appendix. Its corresponding far field pattern appears in Figure 29.

Correcting the distortion at the lens steers the main beam back to boresite, but does not improve the sidelobe levels (Figure 30). Phase-only corrections at the feed lowers the sidelobe level somewhat, but does not correct the main beam steering error (Figure 31). Combining these two corrections produces a more acceptable pattern (Figure 32); however, the sidelobes are 10 dB higher than the quiescent no element failure pattern. Phase and amplitude control at the feed offers considerable improvement over phase-only compensation (Figure 33). The feed and lens amplitude and phase distributions for the last five examples are shown in Tables A18 to A21.

In order to adequately compensate for all the feed displacements and element failures, amplitude and phase controls are required at the feed and phase controls at the lens. The feed element amplitude would only be adjusted when a feed element failed. Otherwise phase only control at the feed and lens provides good correction for the displaced feed.

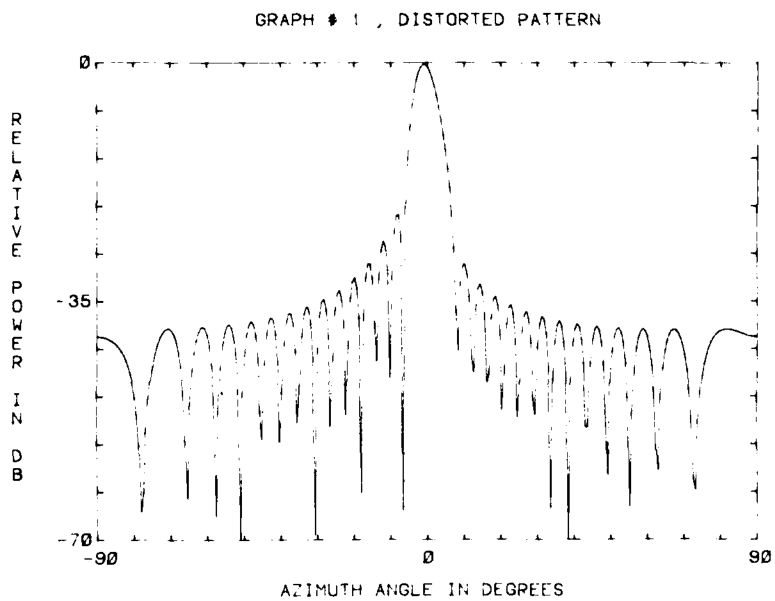

Figure 29. Far Field Pattern Due to an Element Failure in the Feed

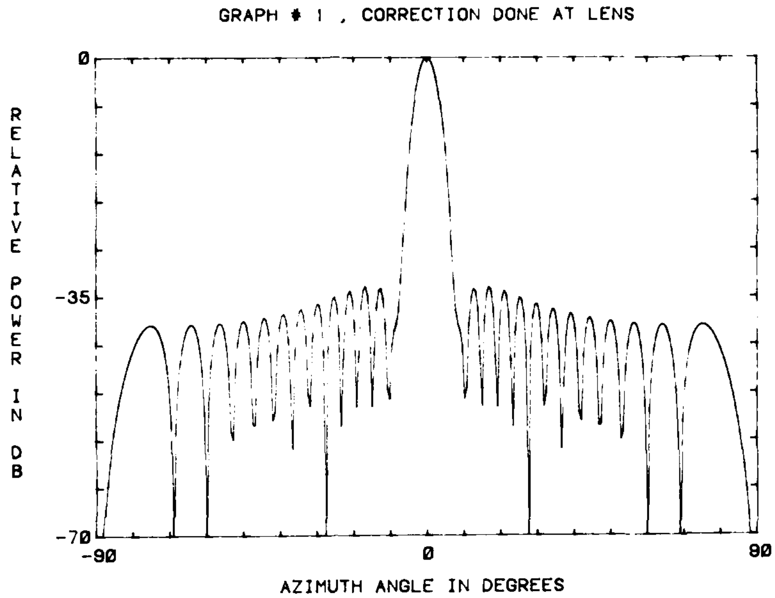

Figure 30. Far Field Pattern Resulting From an Element Failure and Phase Only Lens Compensation

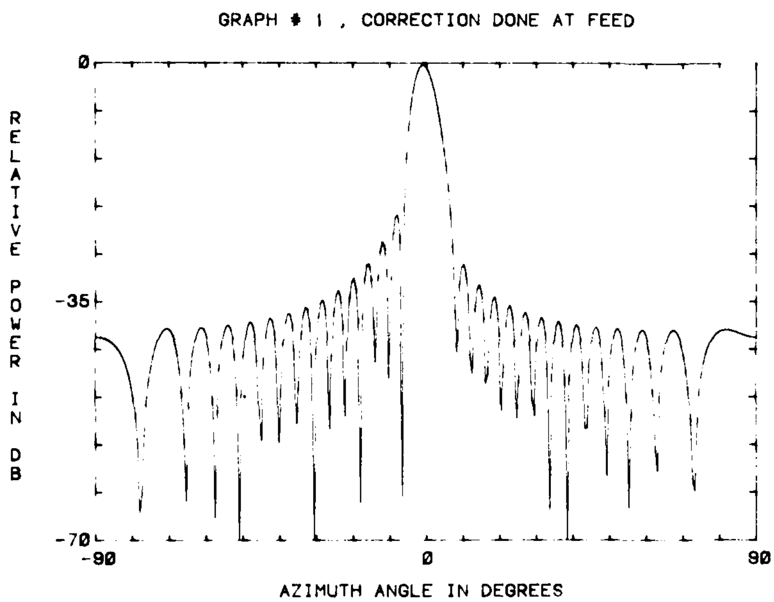

Figure 31. Far Field Pattern Resulting From an Element Failure and Phase Only Feed Compensation

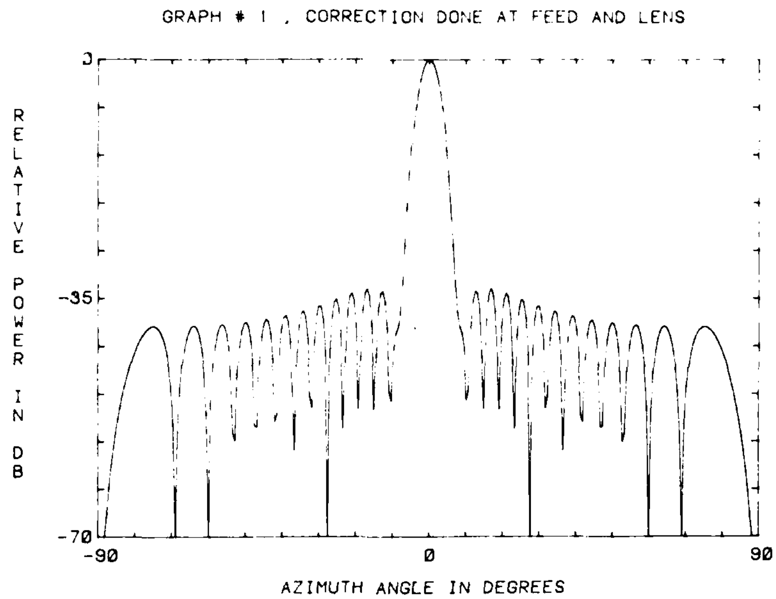

Figure 32. Far Field Pattern Resulting From an Element Failure and Phase Only Feed and Lens Compensation

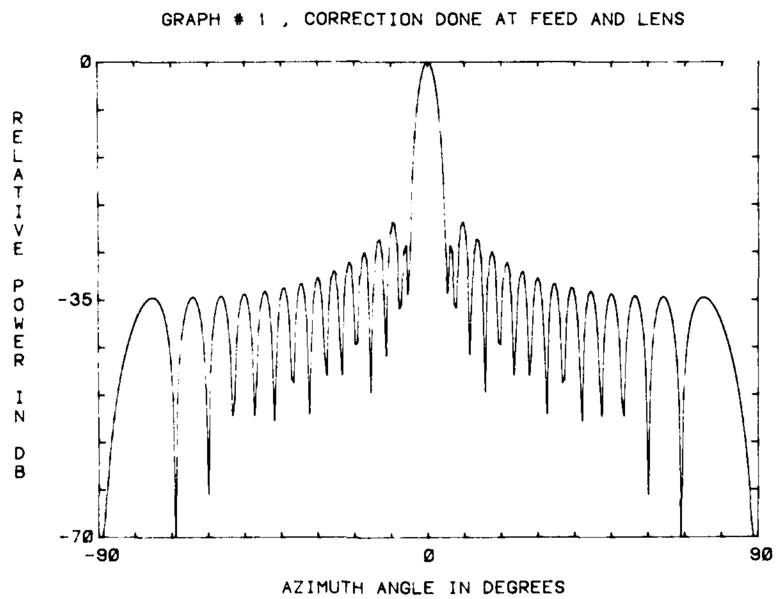

Figure 33. Far Field Pattern Resulting From an Element Failure and Amplitude and Phase Feed and Phase Only Lens Correction

A method of determining the element locations is the crux of the compensation technique. This presents several problems. First, the physical location of each feed element relative to the lens must be known. Laser range finding and triangulation systems could accurately locate parts of the feed relative to the lens.[2,3,4,5] Element locations would have to be interpolated between the known feed locations determined by laser range finding. Consequently, an error exists in the coordinates for the feed element and the feed correction also has an associated error.

A second problem with the realization of feed compensation is the implicit assumption that the lens is not distorted. If the lens is distorted, even some form of detecting the distortion and correcting for it is needed.[6] Otherwise, the lens deformations will also distort the far field pattern and the feed compensation will not correct this distortion. Thus, some form of lens distortion compensation must go hand-in-hand with the feed compensation in an actual system.

A third difficulty arises when the phase centers of the elements vary from element to element and are not the same as the physical centers of the elements.[7] This occurs in the presence of mutual coupling or a ground plane. Since the phase centers of the elements are not exactly known, the distances between the feed and lens elements are not exactly known. An error in these distances degrades the compensation performance.

The operational and signal bandwidths of the system generate further complications. Operational bandwidth is the band of frequencies over which the system may operate. Changing the frequency of operation requires a change in the feed compensation, because the element locations (in λ) change inversely with frequency. The compensation also assumed a monochromatic signal. An actual system will have a signal bandwidth. Compensation at the center frequency corrects for that single frequency, but not for other frequencies within the bandwidth.

In spite of the problems mentioned above, feed compensation may be a necessity in large low sidelobe space fed lens phased array antennas. Some of the errors can be corrected or improved, while others limit the extent of the compensation.

4. CONCLUSIONS

Low sidelobe space fed lens antennas are sensitive to any feed displacement. Four types of distortions were considered in this report: (1) linear tilt, (2) fold-in, (3) parallel displacement, and (4) perpendicular displacement. These distortions raised the sidelobe level and steered the main beam off boresite. Phase only lens

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(Due to the large number of references cited above, they will not be listed here. See References, page 35.)

corrections steered the main beam back to boresite and phase only feed corrections almost brought the sidelobe levels back to their original state. Amplitude and phase corrections at the feed offered no improvements over the phase-only alternative when the feed was displaced. On the other hand, amplitude and phase corrections at the feed were necessary to compensate for element failure.

Phase shifter quantization degrades the antenna's performance by approximating the feed element phase and the lens correction. A broad element pattern has little impact on the correction techniques. Models for both these effects showed the impact on the far field pattern.

The compensation techniques were also tried in cases with a feed element failure. Phase-only compensation at the feed and lens offered an improvement over the distorted pattern. In order to regain a far field comparable with the quiescent pattern, amplitude and phase control are required at their feed.

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Appendix A

Amplitude and Phase Values for the Field and Lens Elements

The following tables show the amplitude and phase values at the feed and lens elements of the space feed antenna discussed in the text. Each table in the Appendix has a corresponding figure showing its far field pattern in this report.

At the top of every table are the feed parameters. Each feed element and its associated phase and amplitude settings are shown. Next, the 30 lens elements with the relative amplitude and phase values of the fields radiated by the feed appear under "Lens Parameters." The phase shifters in the lens are set at the "Correction" value or C_n. All phase values are in radians.

Table A1. Feed and Lens Distribution Associated With Figure 3

FEED PARAMETERS
NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.390	2.865
2	0.748	3.016
3	1.000	3.089
4	1.000	3.089
5	0.748	3.016
6	0.390	2.865

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.032	0.667	-0.667
2	0.045	1.806	-1.806
3	0.059	2.871	-2.871
4	0.075	3.860	-3.860
5	0.092	-1.509	1.509
6	0.111	-0.673	0.673
7	0.130	0.084	-0.084
8	0.149	0.761	-0.761
9	0.167	1.357	-1.357
10	0.185	1.869	-1.869
11	0.201	2.298	-2.298
12	0.215	2.642	-2.642
13	0.226	2.901	-2.901
14	0.233	3.074	-3.074
15	0.237	3.161	-3.161
16	0.237	3.161	-3.161
17	0.233	3.074	-3.074
18	0.226	2.901	-2.901
19	0.215	2.642	-2.642
20	0.201	2.298	-2.298
21	0.185	1.869	-1.869
22	0.167	1.357	-1.357
23	0.149	0.761	-0.761
24	0.130	0.084	-0.084
25	0.111	-0.673	0.673
26	0.092	-1.509	1.509
27	0.075	3.860	-3.860
28	0.059	2.871	-2.871
29	0.045	1.806	-1.806
30	0.032	0.667	-0.667

Table A2. Feed and Lens Distribution Associated With Figure 4

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 10 DEGREES
LATERAL DISPLACEMENT 0 WAVELENGTHS
PERPENDICULAR DISPLACEMENT 0 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.390	2.865
2	0.748	3.016
3	1.000	3.089
4	1.000	3.089
5	0.748	3.016
6	0.390	2.865

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.013	3.909	-3.909
2	0.011	-1.244	1.244
3	0.008	-0.181	0.181
4	0.003	0.832	-0.832
5	0.003	-1.497	1.497
6	0.012	-0.633	0.633
7	0.023	0.126	-0.126
8	0.035	0.801	-0.801
9	0.050	1.394	-1.394
10	0.067	1.903	-1.903
11	0.085	2.328	-2.328
12	0.104	2.669	-2.669
13	0.124	2.924	-2.924
14	0.144	3.093	-3.093
15	0.164	3.175	-3.175
16	0.182	3.171	-3.171
17	0.198	3.081	-3.081
18	0.212	2.904	-2.904
19	0.222	2.641	-2.641
20	0.230	2.293	-2.293
21	0.233	1.860	-1.860
22	0.234	1.344	-1.344
23	0.230	0.745	-0.745
24	0.223	0.065	-0.065
25	0.214	-0.695	0.695
26	0.202	-1.533	1.533
27	0.188	3.835	-3.835
28	0.172	2.844	-2.844
29	0.156	1.780	-1.780
30	0.139	0.645	-0.645

Table A3. Feed and Lens Distribution Associated With Figure 5

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 10 DEGREES
LATERAL DISPLACEMENT 0 WAVELENGTHS
LONGITUDINAL DISPLACEMENT 0 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.390	2.865
2	0.748	3.016
3	1.000	3.089
4	1.000	3.089
5	0.748	3.016
6	0.390	2.865

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.068	0.992	-0.667
2	0.075	1.984	-1.806
3	0.084	2.911	-2.871
4	0.094	3.777	-3.860
5	0.106	4.581	1.509
6	0.119	-0.961	0.673
7	0.133	-0.285	-0.084
8	0.147	0.323	-0.761
9	0.161	0.862	-1.357
10	0.175	1.328	-1.869
11	0.187	1.719	-2.298
12	0.198	2.035	-2.642
13	0.206	2.272	-2.901
14	0.212	2.431	-3.074
15	0.215	2.511	-3.161
16	0.215	2.511	-3.161
17	0.212	2.431	-3.074
18	0.206	2.272	-2.901
19	0.198	2.035	-2.642
20	0.187	1.719	-2.298
21	0.175	1.328	-1.869
22	0.161	0.862	-1.357
23	0.147	0.323	-0.761
24	0.133	-0.285	-0.084
25	0.119	-0.961	0.673
26	0.106	4.581	1.509
27	0.094	3.777	-3.860
28	0.084	2.911	-2.871
29	0.075	1.984	-1.806
30	0.068	0.992	-0.667

Table A4. Feed and Lens Distribution Associated With Figure 6

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 0 DEGREES
LATERAL DISPLACEMENT 2 WAVELENGTHS
LONGITUDINAL DISPLACEMENT 0 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.390	2.865
2	0.748	3.016
3	1.000	3.089
4	1.000	3.089
5	0.748	3.016
6	0.390	2.865

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.005	4.387	-3.650
2	0.006	-0.096	-3.799
3	0.006	1.656	1.444
4	0.006	3.356	0.284
5	0.006	-1.285	-0.858
6	0.006	0.289	-1.952
7	0.005	1.771	-2.985
8	0.004	3.075	-3.951
9	0.002	3.650	1.438
10	0.004	3.799	0.617
11	0.009	-1.444	-0.128
12	0.016	-0.284	-0.794
13	0.024	0.858	-1.381
14	0.035	1.952	-1.886
15	0.047	2.985	-2.309
16	0.062	3.951	-2.649
17	0.079	-1.438	-2.905
18	0.097	-0.617	-3.075
19	0.116	0.128	-3.161
20	0.137	0.794	-3.161
21	0.157	1.381	-3.075
22	0.176	1.886	-2.905
23	0.195	2.309	-2.649
24	0.210	2.649	-2.309
25	0.223	2.905	-1.886
26	0.232	3.075	-1.381
27	0.236	3.161	-0.794
28	0.236	3.161	-0.128
29	0.232	3.075	0.617
30	0.223	2.905	1.438

Table A5. Feed and Lens Distribution Associated With Figure 7

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 0 DEGREES
LATERAL DISPLACEMENT 0 WAVELENGTHS
LONGITUDINAL DISPLACEMENT 2 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.390	2.865
2	0.748	3.016
3	1.000	3.089
4	1.000	3.089
5	0.748	3.016
6	0.390	2.865

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.036	1.594	-0.667
2	0.047	2.612	-1.806
3	0.059	3.565	-2.871
4	0.073	4.453	-3.860
5	0.088	-1.011	1.509
6	0.104	-0.261	0.673
7	0.120	0.417	-0.084
8	0.137	1.024	-0.761
9	0.153	1.557	-1.357
10	0.168	2.016	-1.869
11	0.182	2.400	-2.298
12	0.194	2.707	-2.642
13	0.203	2.939	-2.901
14	0.209	3.093	-3.074
15	0.213	3.171	-3.161
16	0.213	3.171	-3.161
17	0.209	3.093	-3.074
18	0.203	2.939	-2.901
19	0.194	2.707	-2.642
20	0.182	2.400	-2.298
21	0.168	2.016	-1.869
22	0.153	1.557	-1.357
23	0.137	1.024	-0.761
24	0.120	0.417	-0.084
25	0.104	-0.261	0.673
26	0.088	-1.011	1.509
27	0.073	4.453	-3.860
28	0.059	3.565	-2.871
29	0.047	2.612	-1.806
30	0.036	1.594	-0.667

Table A6. Feed and Lens Distribution Associated With Figure 8

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 10 DEGREES
LATERAL DISPLACEMENT 2 WAVELENGTHS
LONGITUDINAL DISPLACEMENT 2 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.390	2.865
2	0.748	3.016
3	1.000	3.089
4	1.000	3.089
5	0.748	3.016
6	0.390	2.865

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.013	0.005	-0.667
2	0.013	1.292	-1.806
3	0.012	2.522	-2.871
4	0.011	3.696	-3.860
5	0.009	-1.464	1.509
6	0.006	-0.364	0.673
7	0.002	1.044	-0.084
8	0.004	4.165	-0.761
9	0.011	-1.116	-1.357
10	0.020	-0.314	-1.869
11	0.030	0.390	-2.298
12	0.042	1.011	-2.642
13	0.055	1.554	-2.901
14	0.069	2.019	-3.074
15	0.084	2.407	-3.161
16	0.100	2.717	-3.161
17	0.116	2.950	-3.074
18	0.132	3.104	-2.901
19	0.148	3.180	-2.642
20	0.163	3.178	-2.298
21	0.176	3.097	-1.869
22	0.188	2.939	-1.357
23	0.197	2.703	-0.761
24	0.204	2.389	-0.084
25	0.209	1.999	0.673
26	0.210	1.533	1.509
27	0.210	0.992	-3.860
28	0.206	0.376	-2.871
29	0.201	-0.312	-1.806
30	0.193	-1.073	-0.667

Table A7. Feed and Lens Distribution Associated With Figure 14

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 10 DEGREES
LATERAL DISPLACEMENT 0 WAVELENGTHS
PERPENDICULAR DISPLACEMENT 0 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.390	4.241
2	0.748	3.829
3	1.000	3.360
4	1.000	2.822
5	0.748	2.206
6	0.390	1.492

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.041	0.649	-0.667
2	0.054	1.796	-1.806
3	0.068	2.867	-2.871
4	0.083	3.861	-3.860
5	0.100	-1.505	1.509
6	0.117	-0.667	0.673
7	0.135	0.091	-0.084
8	0.153	0.769	-0.761
9	0.171	1.364	-1.357
10	0.188	1.877	-1.869
11	0.203	2.305	-2.298
12	0.216	2.648	-2.642
13	0.226	2.906	-2.901
14	0.233	3.077	-3.074
15	0.237	3.162	-3.161
16	0.237	3.161	-3.161
17	0.233	3.072	-3.074
18	0.226	2.898	-2.901
19	0.215	2.637	-2.642
20	0.201	2.291	-2.298
21	0.185	1.861	-1.869
22	0.167	1.347	-1.357
23	0.148	0.751	-0.761
24	0.129	0.073	-0.084
25	0.109	-0 [illegible]84	0.673
26	0.091	[illegible] 19	1.509
27	0.073	3.852	-3.860
28	0.057	2.865	-2.871
29	0.042	1.806	-1.806
30	0.029	0.677	-0.667

Table A8. Feed and Lens Distribution Associated With Figure 15

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 10 DEGREES
LATERAL DISPLACEMENT 0 WAVELENGTHS
LONGITUDINAL DISPLACEMENT 0 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.390	1.479
2	0.748	2.204
3	1.000	2.825
4	1.000	2.825
5	0.748	2.204
6	0.390	1.479

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.037	0.543	-0.667
2	0.050	1.732	-1.806
3	0.064	2.827	-2.871
4	0.080	3.836	-3.860
5	0.097	-1.521	1.509
6	0.114	-0.678	0.673
7	0.133	0.084	-0.084
8	0.151	0.763	-0.761
9	0.169	1.359	-1.357
10	0.186	1.872	-1.869
11	0.202	2.301	-2.298
12	0.215	2.645	-2.642
13	0.225	2.903	-2.901
14	0.232	3.075	-3.074
15	0.236	3.162	-3.161
16	0.236	3.162	-3.161
17	0.232	3.075	-3.074
18	0.225	2.903	-2.901
19	0.215	2.645	-2.642
20	0.202	2.301	-2.298
21	0.186	1.872	-1.869
22	0.169	1.359	-1.357
23	0.151	0.763	-0.761
24	0.133	0.084	-0.084
25	0.114	-0.678	0.673
26	0.097	-1.521	1.509
27	0.080	3.836	-3.860
28	0.064	2.827	-2.871
29	0.050	1.732	-1.806
30	0.037	0.543	-0.667

Table A9. Feed and Lens Distribution Associated With Figure 16

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 0 DEGREES
LATERAL DISPLACEMENT 2 WAVELENGTHS
LONGITUDINAL DISPLACEMENT 0 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.390	2.569
2	0.748	2.404
3	1.000	2.164
4	1.000	1.840
5	0.748	1.416
6	0.390	0.852

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.042	2.733	-0.667
2	0.054	4.162	-1.806
3	0.068	-0.764	-2.871
4	0.082	0.522	-3.860
5	0.098	1.737	1.509
6	0.114	2.879	0.673
7	0.132	3.948	-0.084
8	0.149	-1.341	-0.761
9	0.166	-0.423	-1.357
10	0.183	0.416	-1.869
11	0.198	1.177	-2.298
12	0.211	1.856	-2.642
13	0.222	2.454	-2.901
14	0.230	2.969	-3.074
15	0.235	3.400	-3.161
16	0.236	3.745	-3.161
17	0.233	4.005	-3.074
18	0.227	4.178	-2.901
19	0.217	4.265	-2.642
20	0.204	4.265	-2.298
21	0.188	4.178	-1.869
22	0.171	4.003	-1.357
23	0.151	3.743	-0.761
24	0.131	3.395	-0.084
25	0.111	2.962	0.673
26	0.092	2.444	1.509
27	0.073	1.839	-3.860
28	0.056	1.150	-2.871
29	0.041	0.372	-1.806
30	0.028	-0.499	-0.667

Table A10. Feed and Lens Distribution Associated With Figure 17

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 0 DEGREES
LATERAL DISPLACEMENT 0 WAVELENGTHS
LONGITUDINAL DISPLACEMENT 2 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.390	2.991
2	0.748	3.138
3	1.000	3.209
4	1.000	3.209
5	0.748	3.138
6	0.390	2.991

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.046	1.361	-0.667
2	0.058	2.400	-1.806
3	0.071	3.371	-2.871
4	0.085	4.272	-3.860
5	0.100	-1.180	1.509
6	0.116	-0.421	0.673
7	0.131	0.266	-0.084
8	0.146	0.879	-0.761
9	0.161	1.419	-1.357
10	0.175	1.882	-1.869
11	0.187	2.270	-2.298
12	0.197	2.581	-2.642
13	0.205	2.815	-2.901
14	0.210	2.971	-3.074
15	0.213	3.049	-3.161
16	0.213	3.049	-3.161
17	0.210	2.971	-3.074
18	0.205	2.815	-2.901
19	0.197	2.581	-2.642
20	0.187	2.270	-2.298
21	0.175	1.882	-1.869
22	0.161	1.419	-1.357
23	0.146	0.879	-0.761
24	0.131	0.266	-0.084
25	0.116	-0.421	0.673
26	0.100	-1.180	1.509
27	0.085	4.272	-3.860
28	0.071	3.371	-2.871
29	0.058	2.400	-1.806
30	0.046	1.361	-0.667

Table A11. Feed and Lens Distribution Associated With Figure 18

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 10 DEGREES
LATERAL DISPLACEMENT 2 WAVELENGTHS
LONGITUDINAL DISPLACEMENT 2 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.390	3.644
2	0.748	2.915
3	1.000	2.146
4	1.000	1.319
5	0.748	0.418
6	0.390	-0.577

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.064	4.340	-0.667
2	0.075	-0.652	-1.806
3	0.086	0.578	-2.871
4	0.098	1.745	-3.860
5	0.111	2.847	1.509
6	0.124	3.883	0.673
7	0.137	-1.432	-0.084
8	0.150	-0.532	-0.761
9	0.163	0.298	-1.357
10	0.175	1.057	-1.869
11	0.186	1.743	-2.298
12	0.195	2.356	-2.642
13	0.203	2.894	-2.901
14	0.208	3.358	-3.074
15	0.212	3.745	-3.161
16	0.213	4.055	-3.161
17	0.211	4.288	-3.074
18	0.207	4.443	-2.901
19	0.200	4.521	-2.642
20	0.190	4.521	-2.298
21	0.179	4.442	-1.869
22	0.166	4.286	-1.357
23	0.151	4.053	-0.761
24	0.135	3.743	-0.084
25	0.119	3.356	0.673
26	0.103	2.894	1.509
27	0.087	2.358	-3.860
28	0.071	1.748	-2.871
29	0.057	1.066	-1.806
30	0.043	0.314	-0.667

Table A12. Feed and Lens Distribution Associated With Figure 24

FEED PARAMETERS
NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.443	3.142
2	0.772	3.142
3	1.000	3.142
4	1.000	3.142
5	0.772	3.142
6	0.443	3.142

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.025	1.169	-1.178
2	0.035	2.140	-2.160
3	0.047	3.090	-3.142
4	0.062	3.997	-3.927
5	0.078	-1.434	1.374
6	0.097	-0.646	0.589
7	0.117	0.075	0.000
8	0.139	0.722	-0.785
9	0.160	1.294	-1.374
10	0.180	1.788	-1.767
11	0.199	2.203	-2.160
12	0.216	2.536	-2.553
13	0.229	2.787	-2.749
14	0.239	2.954	-2.945
15	0.243	3.038	-2.945
16	0.243	3.038	-2.945
17	0.239	2.954	-2.945
18	0.229	2.787	-2.749
19	0.216	2.536	-2.553
20	0.199	2.203	-2.160
21	0.180	1.788	-1.767
22	0.160	1.294	-1.374
23	0.139	0.722	-0.785
24	0.117	0.075	0.000
25	0.097	-0.646	0.589
26	0.078	-1.434	1.374
27	0.062	3.997	-3.927
28	0.047	3.090	-3.142
29	0.035	2.140	-2.160
30	0.025	1.169	-1.178

Table A13. Feed and Lens Distribution Associated With Figure 25

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 10 DEGREES
LATERAL DISPLACEMENT 2 WAVELENGTHS
LONGITUDINAL DISPLACEMENT 2 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.443	3.142
2	0.772	3.142
3	1.000	3.142
4	1.000	3.142
5	0.772	3.142
6	0.443	3.142

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.011	-0.451	-1.178
2	0.012	0.770	-2.160
3	0.013	1.921	-3.142
4	0.013	2.992	-3.927
5	0.013	3.969	1.374
6	0.012	-1.459	0.589
7	0.011	-0.774	0.000
8	0.011	-0.309	-0.785
9	0.013	0.013	-1.374
10	0.019	0.377	-1.767
11	0.027	0.817	-2.160
12	0.038	1.276	-2.553
13	0.050	1.712	-2.749
14	0.065	2.104	-2.945
15	0.081	2.438	-2.945
16	0.098	2.708	-2.945
17	0.116	2.910	-2.945
18	0.133	3.041	-2.749
19	0.150	3.098	-2.553
20	0.165	3.082	-2.160
21	0.179	2.990	-1.767
22	0.190	2.824	-1.374
23	0.199	2.582	-0.785
24	0.204	2.266	0.000
25	0.207	1.874	0.589
26	0.206	1.409	1.374
27	0.202	0.871	-3.927
28	0.195	0.260	-3.142
29	0.185	-0.422	-2.160
30	0.174	-1.175	-1.178

Table A14. Feed and Lens Distribution Associated With Figure 26

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 10 DEGREES
LATERAL DISPLACEMENT 2 WAVELENGTHS
LONGITUDINAL DISPLACEMENT 2 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.443	3.142
2	0.772	3.142
3	1.000	3.142
4	1.000	3.142
5	0.772	3.142
6	0.443	3.142

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.011	-0.451	0.393
2	0.012	0.770	-0.785
3	0.013	1.921	-1.963
4	0.013	2.992	-2.945
5	0.013	3.969	-3.927
6	0.012	-1.459	1.374
7	0.011	-0.774	0.785
8	0.011	-0.309	0.393
9	0.013	0.013	0.000
10	0.019	0.377	-0.393
11	0.027	0.817	-0.785
12	0.038	1.276	-1.178
13	0.050	1.712	-1.767
14	0.065	2.104	-2.160
15	0.081	2.438	-2.356
16	0.098	2.708	-2.749
17	0.116	2.910	-2.945
18	0.133	3.041	-2.945
19	0.150	3.098	-3.142
20	0.165	3.082	-3.142
21	0.179	2.990	-2.945
22	0.190	2.824	-2.749
23	0.199	2.582	-2.553
24	0.204	2.266	-2.356
25	0.207	1.874	-1.963
26	0.206	1.409	-1.374
27	0.202	0.871	-0.785
28	0.195	0.260	-0.196
29	0.185	-0.422	0.393
30	0.174	-1.175	1.178

Table A15. Feed and Lens Distribution Associated With Figure 27

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 10 DEGREES
LATERAL DISPLACEMENT 2 WAVELENGTHS
LONGITUDINAL DISPLACEMENT 2 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.443	4.320
2	0.772	3.534
3	1.000	2.749
4	1.000	1.963
5	0.772	1.178
6	0.443	0.196

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.037	3.888	-1.178
2	0.046	-1.141	-2.160
3	0.057	0.058	-3.142
4	0.069	1.199	-3.927
5	0.082	2.280	1.374
6	0.095	3.298	0.589
7	0.110	4.251	0.000
8	0.125	-1.146	-0.785
9	0.141	-0.328	-1.374
10	0.156	0.421	-1.767
11	0.171	1.099	-2.160
12	0.184	1.705	-2.553
13	0.196	2.238	-2.749
14	0.205	2.696	-2.945
15	0.212	3.080	-2.945
16	0.216	3.388	-2.945
17	0.217	3.621	-2.945
18	0.215	3.777	-2.749
19	0.209	3.856	-2.553
20	0.200	3.859	-2.160
21	0.188	3.785	-1.767
22	0.173	3.636	-1.374
23	0.157	3.412	-0.785
24	0.140	3.113	0.000
25	0.122	2.740	0.589
26	0.104	2.297	1.374
27	0.086	1.784	-3.927
28	0.070	1.204	-3.142
29	0.055	0.563	-2.160
30	0.042	-0.132	-1.178

Table A16. Feed and Lens Distribution Associated With Figure 28

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 10 DEGREES
LATERAL DISPLACEMENT 2 WAVELENGTHS
LONGITUDINAL DISPLACEMENT 2 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.443	4.320
2	0.772	3.534
3	1.000	2.749
4	1.000	1.963
5	0.772	1.178
6	0.443	0.196

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.037	3.888	-3.927
2	0.046	[illegible]	1.178
3	0.057	0.058	0.000
4	0.069	1.199	-1.178
5	0.082	2.280	-2.356
6	0.095	3.298	-3.338
7	0.110	[illegible]	-4.320
8	0.125	-1.146	1.178
9	0.141	-0.328	0.393
10	0.156	0.421	-0.393
11	[illegible]	1.099	-1.178
12	0.184	1.705	-1.767
13	0.196	2.238	[illegible]
14	0.205	2.696	-2.749
15	0.212	3.080	-3.142
16	0.216	[illegible]	-3.338
17	0.217	3.621	-3.534
18	0.215	3.777	-3.731
19	0.209	3.856	-3.927
20	0.200	3.859	-3.927
21	0.188	[illegible]	-3.731
22	0.173	3.636	[illegible]
23	0.157	3.412	-3.338
24	0.140	3.113	-3.142
25	0.122	2.740	-2.749
26	0.104	2.297	-2.356
27	0.086	1.784	[illegible]
28	0.070	1.204	-1.178
29	0.055	0.563	-0.589
30	[illegible]	-0.132	0.196

Table A17. Feed and Lens Distribution Associated With Figure 29

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 0 DEGREES
LATERAL DISPLACEMENT 0 WAVELENGTHS
LONGITUDINAL DISPLACEMENT 0 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.390	2.865
2	0.748	3.016
3	0.000	3.089
4	1.000	3.089
5	0.748	3.016
6	0.390	2.865

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.030	-1.309	-0.667
2	0.026	0.213	-1.806
3	0.028	1.766	-2.871
4	0.036	3.150	-3.860
5	0.049	4.306	1.509
6	0.064	-0.996	0.673
7	0.081	-0.149	-0.084
8	0.098	0.589	-0.761
9	0.116	1.226	-1.357
10	0.132	1.771	-1.869
11	0.147	2.224	-2.298
12	0.160	2.588	-2.642
13	0.171	2.863	-2.901
14	0.178	3.050	-3.074
15	0.181	3.150	-3.161
16	0.181	3.164	-3.161
17	0.178	3.091	-3.074
18	0.171	2.933	-2.901
19	0.160	2.692	-2.642
20	0.147	2.369	-2.298
21	0.132	1.966	-1.869
22	0.116	1.487	-1.357
23	0.099	0.938	-0.761
24	0.082	0.326	-0.084
25	0.065	-0.336	0.673
26	0.050	-1.023	1.509
27	0.038	4.584	-3.860
28	0.030	3.956	-2.871
29	0.028	3.328	-1.806
30	0.031	2.557	-0.667

Table A18. Feed and Lens Distribution Associated With Figure 30

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 0 DEGREES
LATERAL DISPLACEMENT 0 WAVELENGTHS
LONGITUDINAL DISPLACEMENT 0 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.390	2.865
2	0.748	3.016
3	0.000	3.089
4	1.000	3.089
5	0.748	3.016
6	0.390	2.865

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.030	-1.309	1.309
2	0.026	0.213	-0.213
3	0.028	1.766	-1.766
4	0.036	3.150	-3.150
5	0.049	4.306	-4.306
6	0.064	-0.996	0.996
7	0.081	-0.149	0.149
8	0.098	0.589	-0.589
9	0.116	1.226	-1.226
10	0.132	1.771	-1.771
11	0.147	2.224	-2.224
12	0.160	2.588	-2.588
13	0.171	2.863	-2.863
14	0.178	3.050	-3.050
15	0.181	3.150	-3.150
16	0.181	3.164	-3.164
17	0.178	3.091	-3.091
18	0.171	2.933	-2.933
19	0.160	2.692	-2.692
20	0.147	2.369	-2.369
21	0.132	1.966	-1.966
22	0.116	1.487	-1.487
23	0.099	0.938	-0.938
24	0.082	0.326	-0.326
25	0.065	-0.336	0.336
26	0.050	-1.023	1.023
27	0.038	4.584	-4.584
28	0.030	3.956	-3.956
29	0.028	3.328	-3.328
30	0.031	2.557	-2.557

Table A19. Feed and Lens Distribution Associated With Figure 31

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 0 DEGREES
LATERAL DISPLACEMENT 0 WAVELENGTHS
LONGITUDINAL DISPLACEMENT 0 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.390	2.861
2	0.748	3.019
3	0.000	3.094
4	1.000	3.091
5	0.748	3.012
6	0.390	2.857

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.030	-1.297	-0.667
2	0.026	0.224	-1.806
3	0.028	1.771	-2.871
4	0.036	3.151	-3.860
5	0.049	4.305	1.509
6	0.064	-0.997	0.673
7	0.081	-0.149	-0.084
8	0.099	0.588	-0.761
9	0.116	1.227	-1.357
10	0.133	1.771	-1.869
11	0.148	2.224	-2.298
12	0.160	2.588	-2.642
13	0.171	2.864	-2.901
14	0.178	3.051	-3.074
15	0.181	3.151	-3.161
16	0.181	3.165	-3.161
17	0.178	3.092	-3.074
18	0.170	2.934	-2.901
19	0.160	2.693	-2.642
20	0.147	2.369	-2.298
21	0.132	1.966	-1.869
22	0.116	1.487	-1.357
23	0.099	0.938	-0.761
24	0.081	0.325	-0.084
25	0.065	-0.336	0.673
26	0.050	-1.024	1.509
27	0.038	4.585	-3.860
28	0.030	3.960	-2.871
29	0.028	3.337	-1.806
30	0.031	2.567	-0.667

Table A20. Feed and Lens Distribution Associated With Figure 32

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 0 DEGREES
LATERAL DISPLACEMENT 0 WAVELENGTHS
LONGITUDINAL DISPLACEMENT 0 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.390	2.861
2	0.748	3.019
3	0.000	3.094
4	1.000	3.091
5	0.748	3.012
6	0.390	2.857

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.030	-1.297	1.297
2	0.026	0.224	-0.224
3	0.028	1.771	-1.771
4	0.036	3.151	-3.151
5	0.049	4.305	-4.305
6	0.064	-0.997	0.997
7	0.081	-0.149	0.149
8	0.099	0.588	-0.588
9	0.116	1.227	-1.227
10	0.133	1.771	-1.771
11	0.148	2.224	-2.224
12	0.160	2.588	-2.588
13	0.171	2.864	-2.864
14	0.178	3.051	-3.051
15	0.181	3.151	-3.151
16	0.181	3.165	-3.165
17	0.178	3.092	-3.092
18	0.170	2.934	-2.934
19	0.160	2.693	-2.693
20	0.147	2.369	-2.369
21	0.132	1.966	-1.966
22	0.116	1.487	-1.487
23	0.099	0.938	-0.938
24	0.081	0.325	-0.325
25	0.065	-0.336	0.336
26	0.050	-1.024	1.024
27	0.038	4.585	-4.585
28	0.030	3.960	-3.960
29	0.028	3.337	-3.337
30	0.031	2.567	-2.567

Table A21. Feed and Lens Distribution Associated With Figure 33

FEED PARAMETERS

NUMBER OF ELEMENTS 6
ELEMENT SPACING 0.5 WAVELENGTHS
TILT 0 DEGREES
LATERAL DISPLACEMENT 0 WAVELENGTHS
LONGITUDINAL DISPLACEMENT 0 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE
1	0.133	2.914
2	0.362	3.069
3	0.000	3.137
4	0.946	3.128
5	1.000	3.044
6	0.791	2.885

LENS PARAMETERS

NUMBER OF ELEMENTS 30
ELEMENT SPACING 0.5 WAVELENGTHS

ELEMENT	AMPLITUDE	PHASE	CORRECTION
1	0.069	-1.223	1.223
2	0.072	0.077	-0.077
3	0.076	1.314	-1.314
4	0.082	2.480	-2.480
5	0.089	3.565	-3.565
6	0.098	4.562	-4.562
7	0.109	-0.816	0.816
8	0.120	-0.005	0.005
9	0.132	0.712	-0.712
10	0.143	1.336	-1.336
11	0.154	1.866	-1.866
12	0.163	2.305	-2.305
13	0.171	2.653	-2.653
14	0.176	2.911	-2.911
15	0.179	3.081	-3.081
16	0.179	3.164	-3.164
17	0.176	3.161	-3.161
18	0.171	3.075	-3.075
19	0.164	2.905	-2.905
20	0.154	2.656	-2.656
21	0.144	2.330	-2.330
22	0.133	1.928	-1.928
23	0.121	1.454	-1.454
24	0.110	0.911	-0.911
25	0.100	0.301	-0.301
26	0.091	-0.377	0.377
27	0.083	-1.122	1.122
28	0.077	4.344	-4.344
29	0.073	3.451	-3.451
30	0.070	2.477	-2.477

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